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13. SUPPLEMENTARY NOTES

14. ABSTRACT

The 18th International Colloquium on the Dynamics of Explosions and Reactive Systems was held at the University of Washington from 29 July through 3 August 2001. Two hundred and twenty-nine participants from 21 countries gathered to discuss the latest advances in experimental investigation and mathematical modeling of explosions and reactive systems. Two minisymposia focused on pulsed detonation engines and ram accelerators, while 186 podium presentations and 40 posters covered a broad range of theoretical and experimental topics.

15. SUBJECT TERMS

Combustion, explosions, flames, turbulence, detonations, lasers, diagnostics, modeling, simulation, ram accelerators, engines

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ICDERS

18th International Colloquium on the Dynamics of Explosions and Reactive Systems
July 29 – August 3, 2001
Seattle, Washington

Summary Report

Introduction

The 18th ICDERS was hosted in 2001 by the University of Washington College of Engineering. The purpose of the Colloquium was to provide a forum for the discussion of work on the dynamical aspects of explosions and reactive systems. Throughout the five days of the meeting, 186 presentations and 40 posters addressed recent advances in 41 topic areas. The detailed schedule of daily talks and plenary lectures is described in the printed "Program."

Sponsors

Air Force Office of Scientific Research
Army Research Office
Office of Naval Research
Sandia National Laboratories
University of Washington College of Engineering

Proceedings

Plenary lectures and full papers were published on CD-ROM as the *Proceedings of the 18th International Colloquium on the Dynamics of Explosions and Reactive Systems.*

Organized by

Engineering Professional Programs
College of Engineering
University of Washington
www.engr.washington.edu/epp/

Participants

Country	*Registrants*
Belarus	1
Belgium	3
Canada	18
France	19

Germany	15
Israel	3
Italy	2
Japan	30
Kazakhstan	1
Korea	6
Norway	4
People's Republic of China	3
Poland	7
Republic of China on Taiwan	9
Russia	21
Sweden	5
The Netherlands	1
Ukraine	1
United Kingdom	14
United States	66

Total Countries: 21 Total Registrants: 229

18th International Colloquium
on the

Dynamics of Explosions and Reactive Systems

PROGRAM

July 29–August 3, 2001

Seattle, Washington

Hosted by
College of Engineering
University of Washington
Seattle, Washington, USA

18th ICDERS

ORGANIZED BY

Engineering Professional Programs, College of Engineering, University of Washington, Seattle

SPONSORED BY

College of Engineering, University of Washington; Combustion Research Facility, Sandia National Laboratories; Office of Naval Research; Air Force Office of Scientific Research

RECOGNIZED BY

The Combustion Institute as a Specialist Meeting on the Fluid-Dynamic Aspects of Combustion

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18th International Colloquium on the Dynamics of Explosions and Reactive Systems

July 29–August 3, 2001 • Seattle, Washington

CONTENTS

WELCOME

Welcome to the 18th International Colloquium on the Dynamics of Explosions and Reactive Systems. Following the well established tradition of Colloquia in Brussels (1967), Novosibirsk (1969), Marseilles (1971), San Diego (1973), Bourges (1975), Stockholm (1977), Göttingen (1979), Minsk (1981), Poitiers (1983), Berkeley (1985), Warsaw (1987), Ann Arbor (1989), Nagoya (1991), Coimbra (1993), Boulder (1995), Cracow (1997) and Heidelberg (1999), this Colloquium provides an international forum for reporting recent advances in experimental investigation and mathematical modeling of explosions and reactive systems.

Three plenary lectures survey recent developments and discuss opportunities for further research:

- Problems of Predicting Turbulent Burning Rates by D. Bradley (Leeds University),
- Advanced Laser Diagnostics for Reactive Flows by R.K. Hanson (Stanford University)
- Formation of Nanoparticles in Gaseous Reactive Systems by P. Roth (University of Duisburg).

Minisymposia are organized about two themes: pulsed detonation engines (PDE) and ram accelerators (RAMAC). The former theme is a continuation of a discussion started at the 17th ICDERS. The latter theme is quite appropriate given that much of the recent impetus for RAMAC research derives from the seminal efforts of the University of Washington AERL. During sessions of the Colloquium the 186 podium presentations and the 40 poster presentations cover a broad range of both theoretical and experimental topics.

Without the able support of the University of Washington Engineering Professional Programs staff (Bill Rogers, Director; Jan Kvamme, Assistant Director; Christy Roop, Program Coordinator and Mike Mortensen, Conference Assistant) the organization of the Colloquium would not have been possible.

We gratefully acknowledge the financial support of the Air Force Office of Scientific Research, the Office of Naval Research, and the University of Washington and the in-kind support of the Combustion Research Facility of the Sandia National Laboratories.

J. Ray Bowen, Chair
The 18th ICDERS Host Committee
Seattle, July 2001

MESSAGE FROM PROGRAM COMMITTEE

For over 35 years, ICDERS has provided a unique forum for the discussion of work on the dynamical aspects of explosions and reactive systems. The participants in the 18th ICDERS, will indubitably concur that this tradition has been continued and the vision of the founders has been maintained.

For the 16th ICDERS, held in Krakow in 1997, the Program Committee chaired by Elaine Oran introduced multiple plenary lectures to the program. The 18th ICDERS Program Committee continued this initiative by inviting Derek Bradley, Ron Hanson, and Paul Roth to give plenary lectures. These lectures offer a more in depth view of specialist topics than that afforded by a standard lecture.

The Program Committee functioned as two subcommittees – one for reactive systems chaired by N. Peters and one for detonations and explosions chaired by K. Kailasanath. The review process for contributed papers was modeled on the process used by the Program Committee for the 17th ICDERS. Each abstract was assigned to a subcommittee and reviewed and ranked by at least one member of the Program Committee. Criteria for this ranking were originality, quality, and relevance to the central themes of ICDERS.

The Program Committee encourages authors presenting papers at the Colloquium to submit full-length versions to one of three journals, *Shock Waves*, *Combustion Science and Technology*, or *Combustion Theory and Modelling*. The Editorial Board of each of these journals will conduct independent reviews (beyond the review for paper presentation at the Colloquium) and will make publication decisions according to its standards. Please refer to the 18th ICDERS website for further details.

If you have comments on the current, or suggestions for a future ICDERS program, you are encouraged to direct them to the IDERS board, whose current president and vice president are F. Williams of the University of California at San Diego and E. Oran of the Naval Research Laboratory, respectively.

J. Ray Bowen (Chair) for the Program Committee

PROGRAM COMMITTEE

J. R. Bowen, J. Buckmaster, D. Dunn-Rankin, K. Kailasanath, P. Lindstedt, N. Peters, S. Pope, J. Shepherd, N. N. Smirnov, K. Takayama, P. Wolanski, and A. Oppenheim (Honorary Chair)

GENERAL INFORMATION

Registration Desk / Message Center

The Registration Desk is located in the first floor lobby of Kane Hall. Conference staff will be available throughout the week to assist you and your guests. Messages for colleagues may be posted on the message board. The message number in Kane Hall during the colloquium is 206-543-3247.

Refreshment Breaks

Coffee breaks are scheduled for each morning at 10:10 a.m. Coffee, tea, water and pastries will be available at the morning breaks. Soda, juice and coffee will be available at the mid-afternoon breaks. The Tuesday and Thursday afternoon breaks will be served in the Walker-Ames Room together with Poster Sessions on those days.

Name Badges

Please wear your name badge at all times. Badges are required for admission to technical sessions and receptions.

No Smoking

Please observe the no smoking policy inside buildings on campus.

Tickets

Tickets for the Wednesday excursion are enclosed in your registration envelope. Please take care to keep event tickets with you. If you purchased tickets for the Jazz Concert or the Banquet, those tickets have also been enclosed in your registration envelope.

GENERAL INFORMATION

Plenary Lectures

Invited speakers will be featured in morning plenary sessions on Monday, Tuesday and Wednesday. The Plenary lectures are :

Monday: D. Bradley
"Problems of Predicting Turbulent Burning Rates"

Tuesday: R. K. Hanson
"Advanced Laser Diagnostics for Reactive Flows"

Wednesday: P. Roth
"Formation of Nanoparticles in Gaseous Reactive Systems"

Poster Sessions

Two poster sessions featuring 40 posters will be presented. Poster sessions are scheduled for Tuesday and Thursday beginning at 2:50 p.m. in the Walker Ames Room, 2nd floor, Kane Hall. This room will be open during colloquium hours to provide additional opportunities to view the posters and to meet informally with colleagues.

Information for Poster Presenters

Poster boards measure 48" high by 72" wide (122 cm x 182 cm). For each poster paper, a specific board has been assigned.

Poster Session I: Tuesday, July 31, 2:50 p.m.
Set-up time: beginning at noon, Monday, July 30; remove by 10:30 a.m. Wednesday.

Poster Session II: Thursday, August 2, 2:50 p.m.
Set-up time: beginning at noon Wednesday, August 1; remove by 10:30 a.m. Friday.

Information for Podium Presenters

A Speaker Preparation Room is located in Kane Hall, Room 234. Speakers may organize and preview presentation materials in this room.

SPECIAL EVENTS

Opening Reception

Sunday, July 29 *4:00–6:00 p.m.*
McMahon Hall Patio, UW campus
Join your friends and colleagues for an informal reception. Northwest wines and microbrews will be featured along with a selection of light hors d'oeuvres.
Reception is complimentary with registration.

Jazz Concert

Monday, July 30 *7:30 p.m.*
Brechemin Auditorium, Music Building, UW campus
Local jazz trio, New Stories, features Marc Seales on piano, Doug Miller on bass, and John Bishop on drums. Tickets are still available and may be purchased at the Registration Desk.
Ticket cost: $20 per person.

Excursion: Puget Sound Cruise and Salmon Barbecue

Wednesday, August 1 *depart campus at 4 p.m.*
Tillicum Village, Blake Island
Guests will board a boat on the Seattle waterfront and enjoy a narrated harbor cruise while enroute to Tillicum Village on Blake Island. Dinner is served in the traditionally-styled cedar longhouse. The salmon is cooked over an open fire on cedar stakes in the ancient Northwest Coast Native American fashion. A stage presentation highlighting traditional dances and legends follows dinner. Guests may also explore the Blake Island beaches and nature trails. The return cruise features views of the Seattle's nighttime skyline from the waters of Elliott Bay.

3:50 Buses begin loading; gather at flagpole on Memorial Lane, behind Kane Hall
4:00 Buses depart for Seattle waterfront
Argosy boat loads at Pier 55, Seattle waterfront
4:30 Cruise, harbor tour, salmon dinner, entertainment
Tillicum Village, Blake Island
8:00 Return cruise

This excursion is complimentary with registration. Guest tickets may be purchased at the Registration Desk.
Adult Guest Ticket: $60; Child Ticket (12 & under): $30

GUEST PROGRAM

18th ICDERS Banquet

Thursday, August 2 *6:30 p.m. Social Hour*
Faculty Club *7:30 p.m. Dinner and Program*

The 18th ICDERS Banquet will be held on Thursday evening in the Faculty Club on campus overlooking Lake Washington. Wine, beer and cocktails will be available for purchase during the social hour.

Dinner Menu:
hosted wine, salad, baked breast of chicken filled with roasted peppers and prosciutto over fresh rosemary vin blanc, fresh vegetables, rolls and butter
Dessert: fresh fruit shortcake and coffee

Please check in with the Registration Desk if you wish to request a vegetarian entree.

Tickets for this optional event may still be available.
Tickets: $45 per person

Farewell Party

Friday, August 3 *4:45 p.m.*
Walker-Ames Room, Kane Hall
Complimentary with registration.

Wrap up your week with your colleagues and friends at the 18th ICDERS Farewell Party. This event will be held in the Walker-Ames Room and will feature light hors d'oeuvres and northwest beverages.

Accompanying Guest Program

The accompanying guest program offers the opportunity to get reacquainted with old friends or meet fellow travelers. Guest registration includes a tote bag with maps and tour information, Sunday Opening Reception, Monday breakfast and guest orientation followed by a motorcoach tour of Seattle, Wednesday evening cruise to Blake Island with a salmon dinner at Tillicum Village and the Friday Farewell Party.

The Monday breakfast and guest orientation will be held in the Faculty Club beginning at 8:30 a.m. The tour of Seattle will depart at 10:00 a.m. and return visitors to campus by 2:00 p.m.

Guest Registration Fee: $150

8:55 AM — **KANE 210**

CELLULAR STRUCTURE I

Session Chairs: J. Shepherd and M. Lefebvre

8:55 On the Origin of the Double Cellular Structure of Detonation in Gaseous Nitromethane (#159)
N. Lamoureux, C. Matignon, M.-O. Sturtzer, D. Desbordes, H.-N. Presles

9:20 A Numerical Study of Hydrogen/Air Detonation Using a Pressure Dependent Stanford Model: Formation and Burning of Unreacted Gas Pocket (#79)
Nobuyuki Tsuboi, Hiroshi Shimizu, A.Koichi Hayashi, Yoichiro Matsumoto

9:45 Numerical Investigation of Transverse Wave Structures in Two-Dimensional H2-O2-Diluent Detonations (#207)
Kazuaki Inaba, Akiko Matsuo, Katsumi Tanaka

8:55 AM — **KANE 220**

EXPLOSION PHYSICS

Session Chair: H. Schneider

8:55 Pressure Diagnostics of Combustion Following an Explosion (#8)
A.K. Oppenheim, T-H Sum

9:20 Mixing-Controlled Exothermic Fields in Explosions (#188)
A.L. Kuhl, R. . Ferguson

9:45 Explosion-Induced Combustion of Hydrocarbon Clouds in a Chamber (#62)
Peter Neuwald, Heinz Reichenbach, Allen L. Kuhl

8:55 AM — **KANE 120**

PREMIXED TURBULENT FLAMES I

Session Chairs: B. Bai and M. Lawes

8:55 Surface Density Measurements for Freely-Propagating Premixed Turbulent Flames at Various Lewis Numbers (#40)
B. Renou, A. Mura, E. Samson, A. Boukhalfa

9:20 Direct Numerical Simulation of a Statistically Stationary Turbulent Premixed Flame (#161)
Raphael Hauguel, Pascale Domingo, Julien Réveillon, Laurent Guichard-Vervisch

9:45 Heat Loss Rates from Hydrogen-Air Turbulent Flames in Tubes (#139)
M. Kuznetsov, I. Matsukov, S. Dorofeev

10:30 AM — **KANE 120**

PLENARY LECTURE I

10:30 Problems of Predicting Turbulent Burning Rates (#P1)
Derek Bradley

11:20 AM — **KANE 210**

CELLULAR STRUCTURE II

Session Chairs: P. Van Tiggelen and L. Bauwens

11:20 Interaction between Shock and Detonation Waves (#13)
Kunio Terao, Takayuki Yoshida, Kazuaki Kishi, Kazuhiro Ishii

11:45 Measurement of Surface Pressure with Pressure Sensitive Paint in a Detonation Tube (#201)
Yukihiro Sukawa, Koichi Hayashi

12:10 Cellular Structure of Spray Detonation (#23)
S.A. Zhdan, E.S. Prokhorov

11:20 AM — **KANE 220**

GAS EXPLOSIONS

Session Chairs: S. Murray and J. Pascaud

11:20 Review of Contributions of Fraunhofer ICT to Gas Explosion Research - Illustrated by Film Documents (#148)
Helmut Schneider, Gesa Langer, Norbert Eisenreich, Wolfgang Liehmann

11:45 Time Resolved Flow Characteristics of Confined Turbulent Gaseous Explosions (#164)
R.P. Lindstedt, H.A. McCann

12:10 Characterisation of Confined Turbulent Gas Explosions with Reference to Protection Methodologies (#189)
C.L. Gardner, H.N. Phylaktou, G.E. Andrews

11:20 AM — **KANE 120**

PREMIXED TURBULENT FLAMES II

Session Chairs: J. Reveillon and Y. Zhang

11:20 On Accuracy of the Turbulent Burning Velocity Measured in a Cruciform Burner using Ion-Probe Sensors (#12)
W.J. Lin, R.C. Su, S.S. Shy

11:45 Simulations of Premixed Turbulent Stagnation Flames with a Flame Speed Closure Model (#46)
Andrei N. Lipatnikov, Jerzy Chomiak

12:10 Some Aspects on Level-set Modelling of Premixed Turbulent Combustion (#162)
Per Nilsson, Xue-Song Bai

2:00 PM — **KANE 210**

DETONATION STRUCTURE

Session Chairs: A. Kuhl and A. Matsuo

2:00 Direct Observations of Reaction Zone Structure in Propagating Detonations (#137)
F. Pintgen, C. Eckett, J. Austin, J.E. Shepherd

2:25 On the Location of the Chapman-Jouguet Surface in Gaseous Detonations Close to the Limit of Propagation (#156)
Michael Weber, Herbert Olivier, Hans Grönig, Jörg Biegling

2:50 Temperature Profiles and their Influence on the ZND Detonation Structure (#178)
Luc Bauwens, D. Scott Stewart

2:00 PM — **1KANE 220**

CONDENSED PHASE EXPLOSIONS/DETONATIONS

Session Chair: B. Gelfand

2:00 Calculation of the Effect of a Tank Partitioning on a Kerosene Explosion (#221)
J.M. Pascaud, P. Gillard, I. Sochet, J. Brossard, A. Moreno,L. Delrieu

2:25 Detonation Properties of a Model Condensed-Phase Explosive with a Pressure Sensitive Rate Law (#185)
Tariq D. Aslam

2:50 On the Potential of RDX Dust Detonations for Minefield Breaching (#64)
S.B. Murray, F. Zhang, I.O. Moen, P.A. Thibault, M.A. Baker

2:00 PM — **KANE 120**

DUST AND METAL CONTAINING FLAMES

Session Chair: D. Meinköhn

2:00 On Optical Diagnostics for Oxide Particles and Temperature Measurement in Metal Containing Flame (#147)
Igor S. Altman

2:25 Burning Velocity Measurements in Aluminum-Air Suspensions Using Stabilized Dust Flames (#113)
Samuel Goroshin, Massimiliano Kolbe, John Lee

2:50 Interesting Flame Propagation Pattern of Gas Flame Interacting With Dust Deposit (#210)
Shou-Xiang Lu, Li Zhang, Zi-Ru Guo

3:40 PM — **KANE 210**

CELLULAR STRUCTURE III

Session Chair: E. Oran

3:40 The Influence of Detonation Cell Size and Regularity on the Propagation of Gaseous Detonations in Granular Materials (#154)
Torbjorn Slungaard, Tom Engebretsen, Otto K. Sonju

4:05 Multi-Headed Detonations in Oxygen-Aluminum Mixtures: Two-Dimensional Numerical Simulations Using Adaptive Grid Refinement (#136)
Krzysztof Benkiewicz, A. Koichi Hayashi

4:30 Numerical Simulation of Detonation Cells in Hydrogen-Air Mixture with Suspended Aluminum Particles (#163)
Boris Khasainov, Bernard Veyssiere, Wilfrid Ingignoli

3:40 PM — **KANE 220**

DETONATION LIMIT/FAILURE

Session Chairs: S. Ohyagi and A. Vasil'ev

3:40 Detonation Propagation in Hydrogen-Oxygen Mixtures with Concentration Gradients (#153)
Kazuhiro Ishii, Yuichi Takahashi, Takao Tsuboi

4:05 The Failure Mechanism of Detonations Propagating in Porous Wall Tubes (#121)
Matei I Radulescu, Marianne Huot, John H.S. Lee

4:30 Detonation of Propane-Air Mixture in the Perforated Tube and Release of Detonation Products (#104)
V.I. Tarzhanov, V.I. Sdobnov, A.D. Zinchenko, V.A. Ogarkov, V.V. Vlasov

3:40 PM — **KANE 120**

GASLESS AND DUST CONTAINING FLAMES

Session Chairs: TBA

3:40 The Convective-Conductive Mode of the Reaction Zone Propagation: A New Mechanism of Combustion of 'Gasless' Systems (#218)
Boris S.Seplyarskii

4:05 Adiabatic Waves of Gasless Combustion: 3D Simulation (#217)
T.P. Ivleva, A.G. Merzhanov

4:30 Propagation and Extinction of Unsteady Spherical Spray Flame Fronts (#43)
J.B. Greenberg

8:30 AM — **KANE 210**

DDT

Session Chairs: N. Smirnov and G. Ciccarelli

8:30 Effects of Boundary Layers on Shock-flame Interaction and DDT (#27)
Alexei M. Khokhlov, Vadim N. Gamezo, Elaine S. Oran

8:55 DDT in Methane-Air Mixtures (#135)
M. Kuznetsov, G. Ciccarelli, S. Dorofeev, V. Alekseev, Yu. Yankin, T.H. Kim

9:20 The Effect of Nitrates on Deflagration to Detonation Transition (#172)
P. Pinard, A.J. Higgins, J.H.S. Lee, S.B. Murray

9:45 Sensitization of Pentane-Oxygen Mixtures to DDT via Cool Flame Oxidation (#174)
Massimiliano P. Romano, M.I. Radulescu, Andrew J. Higgins, John H.S. Lee

8:30 AM — **KANE 220**

IGNITION PHENOMENA

Session Chair: U. Riedel

8:30 The Droplet Ignition in High Pressure Condition with Natural Convection (#2)
Sang Hun Kang, Seung Wook Baek

8:55 Thermal Explosion in a Droplet-Gas Cloud with Chemical Reaction of General Order (#165)
V. Bykov, I. Goldfarb, V. Gol'dshtein, J.B. Greenberg

9:20 Modeling the Ignition of Sprays (#92)
Chrys Correa, Berthold Schramm, Juergen Warnatz

9:45 Classification of Ignition Processes of Premixed Gases (#17)
Tobias Brutscher, Wolfgang Leuckel, Henning Bockhorn

8:30 AM — **KANE 120**

PREMIXED TURBULENT FLAMES III

Session Chairs: P. Nilsson and A. Lipatnikov

8:30 The Stability of High Speed Turbulent Deflagrations in Fuel-Air Mixtures in an Obstacle Field (#215)
Jenny Chao, John H.S. Lee

8:55 Turbulent Combustion of Spherical Fuel-Rich Hydrogen Pockets (#190)
J.B. Bell, M.S. Day, J.F. Grcar, A.E. Lutz

9:20 Observation of Flame Structure in Low Damköhler Number Fields (#140)
Manabu Fuchihata, Tamio Ida, Yukio Mizutani, Masashi Katsuki

9:45 Investigation of Flamelets in a Turbulent Premixed Flame with a 4-Element Electrostatic Probe and a 2-D LDV (#50)
Junichi Furukawa, Toshisuke Hirano, Forman A. Williams

10:30 AM — **KANE 120**

PLENARY LECTURE II

10:30 Advanced Laser Diagnostics for Reactive Flows (#P2)
R.K. Hanson

11:20 AM — **KANE 210**

SHOCK IGNITION

Session Chairs: K. Takayama and A. Khokhlov

11:20 Effects of Boundary Layers on Ignition Behind Reflected Shocks (#131)
Vadim N. Gamezo, Alexei M. Khokhlov, Elaine S. Oran

11:45 Ethylene Combustion Studied Over a Wide Temperature Range in High Temperature Shock Waves (#225)
P. Cadman, R. J. Bambrey, G.O. Thomas , S.K. Box

12:10 Numerical Studies of Shock Reflection and Ignition (#6)
Boliang Wang, Werner Rehm

11:20 AM — **KANE 220**

CHEMISTRY IN FLAMES I

Session Chair: M. Rabinowitz

11:20 Reactive Flow Calculations with Intrinsic Low Dimensional Manifold Corrections for Convection and Diffusion (#124)
Sandeep Singh, Samuel Paolucci, Joseph M. Powers

11:45 Effect of Nitrogen-Oxide Addition on Low-Temperature Powling-Burner Flames (#87)
Masahiro Furutani, Yasuhiko Ohta, Yasushi Niimi, Masakazu Nose, Shizumo Fujikawa

12:10 Microscopic Shadowgraph and CH-Band Emission Images of Micro-Jet Diffusion Flames (#146)
Tamio Ida, Manabu Fuchihata, Yukio Mizutani

11:20 AM — **KANE 120**

FLAMES

Session Chair: H. Schmidt

11:20 Modelling of Premixed Counterflow Flames Using the Flamelet-Generated Manifold Method (#98)
J.A. van Oijen, L.P.H. de Goey

11:45 Auto-Turbulizating Regimes of Gaseous Spherical Flames (#94)
Ya.A. Gostintsev, A.G. Istratov, N.I. Kidin, V.E. Fortov

12:10 Steep Pressure Interactions With a Methane-Air Flame: The Inclusion of Multi-step Chemistry (#34)
Xin-She Yang, Andy C. McIntosh, John Brindley

2:00 PM — **KANE 210**

DETONATION CHEMISTRY

Session Chair: R. Hanson

2:00 Correlation between Dynamics and Chemical Kinetics Parameters in Detonation Waves (#63)
L. Desweemer, L. Thill, M.H. Lefebvre, P.J. Van Tiggelen

2:25 Two-Step Chemical-Kinetic Descriptions for Detonation Studies (#37)
B. Varatharajan, F.A. Williams

2:00 PM — **KANE 220**

ACOUSTIC PHENOMENA

Session Chair: G. Sharpe

2:00 Propagation of a Flame from the Closed End of a Smooth Horizontal Tube of Variable Length (#110)
Steven Kerampran, Daniel Desbordes, Bernard Veyssiere

2:25 Unstable Explosion Flames and Acoustic Oscillations (#111)
D. Bradley, C.G.W. Sheppard, R. Woolley

2:00 PM — **KANE 120**

RECIPROCATING ENGINES

Session Chair: TBA

2:00 Three-Dimensional Modeling of DI Diesel Engine Combustion using a Flamelet Concept (#158)
Christian Hasse, Norbert Peters

2:25 Application of Pulsed Flame Jet to Compression Ignition Premixed Charge Engine (#85)
Eiichi Murase, Kunihiko Hanada, Takatsugu Katayama

2:50 PM **WALKER AMES ROOM**

POSTER SESSION I

P1 Formation of Nitric Oxide in a Multi-Staged Air LPG Flame (#11)
Han Seok Kim, Seung Wook Baek, Myoung Jong Yu

P2 Triple Flames Around Two Droplets in Flows with Fuel Vapor (#39)
Wei-Hsin Chen

P3 Radiant Ignition Models for Nitramine Propellants (#179)
A. Cohen, K. L. McNesby, R. A. Beyer, R. Wainner

P4 A Thermochemical Code (TDS) for Thermodynamic Calculations of Complex Chemical Systems (#93)
S.A. Gubin

P5 Experimental and Theoretical Investigation of Low Temperature PAH and Soot Formation on Hydrocarbon Flames (#213)
B.A. Urmashev, T.T. Mashan, B.Ya. Kolesnikov, Z.A. Mansurov

P6 Effects Of Variable Density On Mixing Effeciency In Axisymmetric Turbulent Confined Jets (#120)
N. Belaradh, B. Sarh, J.N. Blanchard, I. Gökalp

P7 Towards a Generalized Level-set/in-cell-reconstruction Approach for Accelerating Turbulent Premixed Flames (#116)
Heiko Schmidt, Rupert Klein

P8 Concept of the Limit of Existence of 2-D Steady-State Structure of Fuel Liquid Film under Flame Propagation (#41)
Oleg V. Sharypov, Konstantin A. Medvedko

P9 Modeling of Natural Gas Reburning Process with Pressure Pulsations (#32)
L.Szecówka, R.Jarnicki, A.Teodorczyk

P10 Burning Intensity of Laminar Premixed Flame with Continuous Changing Stretch Rate along the Flame Surface (#149)
Takeshi Yokomori, Masahiko Mizomoto

P11 Numerical Modeling of Detonation Properties for Cast TNT (#134)
Juzhen Cao, Shurong Zhou, Longhe Liang

P12 To the Theory of Ignition and Detonation of Coal Particle Gas Mixtures (#52)
A.Fedorov, T.A. Khmel', Yu. A. Gosteev

P13 Numerical Modeling of Unstable Detonation in Heptane Vapor-Air Mixtures (#130)
Tao Hong, Qin Chengsen

P14 Numerical Study of Detonation Instability for a Two-Step Kinetics Model (#75)
K. Mazaheri, S.A. Hashemi, J.H.Lee

P15 Thermophysical Properties for Dense Multicomponent High Temperature Media (#228)
G.A. Pavlov

P16 Generation of Particle Clouds by means of Pressurized Gas and Gas Generators (#19)
Helmut Schneider, Norbert Eisenreich

P17 Combustion and Explosion of Condensed Reactive Systems as Result of Thermodynamics Stability Loss. New Ideology and Aspects (#226)
O. Shlensky

P18 Thermodynamics of Propane-Air Composition Detonation in the Mixture with Hot Detonation Products (#105)
V.V.Vlasov, V.A.Ogarkov, V.I.Tarzhanov

P19 Quenching of Gas Detonation in Tube by Injection of Inert Gas (#33)
A.Dabkowski, A.Kozak, A.Teodorczyk

P20 Modeling of Turbulent Spray Combustion under Cryogenic and Elevated Pressure Conditions (#10)
D. Schlotz, M. Brunner, E. Gutheil

3:40 PM **KANE 210**

SHOCK INTERACTIONS

Session Chair: J.B. Bell

3:40 Simulations of Shock-Induced Mixing and Combustion of an Acetylene Cloud in a Chamber (#187)
John B. Bell, Marcus S. Day, Vincent E. Beckner, Allen L. Kuhl, P. Neuwald, H. Reichenback

4:05 Visualization of Blast Waves in the Early Stage of Milligram Charge Explosions (#171)
Toshiharu Mizukaki, Harald Kleine, Masahide Katayama, Kazuyoshi Takayama

3:40 PM **KANE 220**

DUSTY SHOCKS/DETONATIONS

Session Chair: P. Wolanski

3:40 On Modeling of Shock Waves Interactions with Combustible Dusty Gas Layers (#14)
R. Klemens, P. Wolanski, P. Kosinski, V.P. Korobeinikov, I.V. Semenov, V.V. Markov

4:05 Shock and Detonation Wave Propagation Along Reactive Particle Cloud in Channel (#54)
A.V. Fedorov, T.A. Khmel'

3:40 PM — KANE 120

MULTI-PHASE COMBUSTION I

Session Chairs: W. Sirignano and P. Domingo

3:40 Control of Single Droplet Combustion and Emission (#142)
S.M. Frolov, V.S. Posvyanskii, V. Ya. Basevich, A.A. Belyaev, O. Esmilaire, C. Jablon, P. Schmelzle

4:05 Oscillations in the Flame Speed of Globally Homogeneous Two Phase Mixtures (#83)
F. Atzler, F.X. Demoulin, M. Lawes, Y. Lee

4:30 Numerical Simulation of Multiphase Reactive Boundary Layer Flow by Mass Split Technique (#211)
Shou-Xiang Lu, Wei-Chen Fan

TECHNICAL PROGRAM WEDNESDAY

8:30 AM — **KANE 210**

DETONATION INITIATION I

Session Chairs: A. Higgins and I. Jeung

8:30 On The Controlled Generation and Detailed Observation of the Onset of Detonation (#51)
Richard Bambrey, Geraint Thomas

8:55 The Influence of Local Disturbances on the Direct Initiation of Detonations (#180)
Hoi Dick Ng, John H.S. Lee

9:20 Diffraction and Re-Initiation of Detonations behind a Backward-facing Step (#132)
Shigeharu Ohyagi, Tetsuro Obara, Shintaro Hoshi, Pin Cai, Teruo Yoshihashi

9:45 On Critical Conditions For Detonation Initiation By Shock Reflection From Rectangular Obstacles (#129)
Geraint Thomas, Simon Ward, Rhys Williams

8:30 AM — **KANE 220**

NON-IDEAL DETONATIONS / FAST DEFLAGRATIONS

Session Chairs: J.H.S. Lee and B. Khasainov

8:30 Photographic Study of the Transition Between the Quasi-Detonation and Choking Regimes (#38)
Daniel H.B. Lieberman, J.H.S. Lee

8:55 Propagation of Fast Deflagrations and Marginal Detonations in Hydrogen-Air-Additive Mixtures (#181)
A. Eder, F. Pintgen, F. Mayinger

9:20 Slow and Fast Deflagrations in Hydrocarbon-Air Mixtures (#117)
M. Kuznetsov, V. Alekseev, Yu. Yankin, S. Dorofeev

9:45 An Experimental Investigation of Flame Deflagration Over Single and Multiple Solid Obstacles (#28)
S. Jarvis, G.K. Hargrave, S.S. Ibrahim

8:30 AM — **KANE 120**

EFFECTS OF ACOUSTIC FIELDS

Session Chair: S. Frolov

8:30 Analysis of Acoustic Wave Transmission through Turbulent, Premixed Flames (#3)
Tim Licuwen

8:55 Flow Velocity Field in a Flame Submitted to Acoustic Modulations (#31)
Sebastien Ducruix, Daniel Durox, Sebastien Candel

9:20 Stabilization of a Non-Premixed Lifted Flame in an Acoustic Field (#61)
David Demare, Françoise Baillot

9:45 Dynamic Characteristics of Kinetically Controlled Combustion and their Impact on Thermoacoustic Instability (#224)
Sungbae Park, Anuradha Annaswamy, Ahmed Ghoniem

10:30 AM — **KANE 120**

PLENARY LECTURE III

10:30 Formation of Nanoparticles in Gaseous Reactive Systems (#P3)
Paul Roth

11:20 AM — **KANE 210**

DETONATION INITIATION II

Session Chairs: M. Short and V. Levin

11:20 A Planar Detonation Initiator (#138)
Scott I. Jackson, Joseph E. Shepherd

11:45 Shock-wave and Jet Initiation of Gaseous Explosions (#143)
O.V. Achasov, O.G. Penyazkov

12:10 Blast Waves Focusing In Hydrogen - Air mixtures (#55)
B. E. Gelfand , A. M. Bartenev , S.V. Khomik , S. M. Medvedev , A. N Polenov, L. H. Josephson, M. Banks

11:20 AM — **KANE 220**

DETONATION DIFFRACTION

Session Chairs: T. Fujiwara and V. Golub

11:20 On the Mechanism of Transition of Self-Sustained Detonation from a Tube to a Half-Space Through an Annular Orifice with Central Obstacle (#96)
B. Khasainov, C. Priault, H.-N. Presles, D. Desbordes

11:45 Critical Tube Measurements at Elevated Initial Mixture Temperatures (#183)
Gaby Ciccarelli

12:10 Self-Organisation of Multifront Structure in Extending Detonation Wave (#1)
Anatoly A. Vasil'ev, Anatoly V. Trotsyuk

11:20 AM — **KANE 120**

PRACTICAL COMBUSTION

Session Chair: TBD

11:20 Quenching Mechanisms of Gaseous Hydrocarbon-Air Flames in Packed Beds (#166)
T.A. Mihalik, J.H.S. Lee, G. Continillo, F.S. Marra

11:45 An Experimental Study of Venting Process of Gas-Air Mixture Combustion in a Cylindrical Vessel (#91)
Yikang Pu, Jun Hu, Fu Jia, Jozef Jarosinski, Jerzy Podfilipski, A. Zawadzki

2:00 PM — **KANE 210**

SHOCK INITIATION / SDT

Session Chairs: G. Thomas and S. Dorofeev

2:00 Evolution of Stable and Pulsating Planar Detonations: Piston and Reflected Shock Initiation (#22)
Gary J. Sharpe

2:25 Propagation Laws and Direct Initiation for Quasi-steady Curved Detonations with Chain-Branching Kinetics (#123)
Mark Short, John B. Bdzil

2:50 Investigation of Lateral Effects on Shock Initiation of a Cylindrical Charge of Homogeneous Nitromethane (#118)
F.X. Jetté, A.C. Yoshinaka, M. Romano, A.J. Higgins, J.H.S. Lee, F. Zhang

3:15 Condition for Explosion by Impact of a Planar, Self-sustained Detonation (#107)
Pierre Vidal, Boris Khasainov

2:00 PM — **KANE 220**

CHEMISTRY IN FLAMES II

Session Chairs: J. Powers and R. Peck

2:00 Ignition of Jet-A Fuel on Silver Oxide Deposits (#66)
Jeff D. Colwell, Robert E. Peck

2:25 Chemical Reactions and Energy Exchange under Thermally Non-Equilibrium Conditions at High Temperatures in N2O-CO System (#204)
Andrei Yu. Starikovskii

2:50 Rate Coefficient Measurements of the Reaction H + O2 + M = HO2 + M from 950K to 1200K (#126)
M.J. Rabinowitz, S.M. Hwang, J.A. Cooke, K.J. DeWitt

2:00 PM — **KANE 120**

NON-PREMIXED TURBULENT FLAMES I

Session Chairs: J. Jarosinski and H. Pitsch

2:00 Structures and Extinctions in Hydrogen Non-Premixed Lifted Turbulent Jet Flame (#152)
Burtsitsig Bai, Yoshiki Shimoshiba, A.Koichi Hayashi, Satoru Ogawa

2:25 Higher-Order Conditional Moment Closure Modeling of Turbulent Nonpremixed Combustion (#194)
Chong M. Cha, Heinz Pitsch

2:50 Large Eddy Simulation of Lifted Turbulent Jet Diffusion Flames (#157)
Pascale Domingo, Luc Vervisch

3:15 Extended LMSE Mixing Model with Chemical Reaction and Injection of Unmixed Concentrations (#49)
M. Gorokhovski, V. Sabel'nikov

3:50 PM — **MEMORIAL LANE**

18TH ICDERS EXCURSION

3:50 Buses begin loading; gather at flagpole on Memorial Lane, behind Kane Hall
4:00 Buses depart for Seattle waterfront
Argosy boat loads at Pier 55, Seattle waterfront
4:30 Cruise, harbor tour, salmon dinner, entertainment
Tillicum Village, Blake Island
8:00 Return cruise

8:30 AM — **KANE 210**

PULSE DETONATION I

Session Chairs: G. Roy and D. Desbordes

8:30 The Influence of Driver Power and Receptor Confinement on Pre-Detonators for Pulse Detonation Engines (#127)
S.B. Murray, F. Zhang, K.B. Gerrard

8:55 Fuel/Air Initiator Development for Pulse Detonation Engines (#232)
Chris Brophy, J. Sinibaldi, D.W. Netzer, N. Setxon

9:20 Peculiarities of Deflagration to Detonation Transition in Gases (#26)
N.N.Smirnov, V.F.Nikitin

9:45 A Study of Detonation Transmission for Facilitating Detonation Initiation in Pulse Detonation Engines (#209)
Chiping Li, K. Kailasanath

8:30 AM — **KANE 220**

LAMINAR FLAMES I

Session Chair: A. McIntosh

8:30 Laminar Flame - Wall Interaction Study: Stretch Effect Analysis (#202)
F. Foucher, S. Burnel, C. Mounaïm-Rouselle, M. Boukhalfa, B. Renou, M. Trinité

8:55 Effects of Strain on Transient Ignition Characteristics of Hydrogen-Air Mixtures Impinging on a Platinum Plate (#200)
Yei-Chin Chao, Hung-Wei Hsu

9:20 Extraction of Basic Flame Properties from Laminar Flame Speed Calculations (#114)
A.I. Gavrikov, A.V. Bezmelnitsyn, A.L. Leliakin, S.B. Dorofeev

9:45 Properties of Propane Flames (#90)
Jozef Jarosinski, Jerzy Podfilipski, Yikang Pu

8:30 AM — **KANE 120**

NON-PREMIXED TURBULENT FLAMES II

Session Chairs: M. Day and C. Cha

8:30 Turbulent Reactive Flow Simulation with Presumed Beta-PDF Combustion Model (#119)
A.Kotchourko, B. Burgeth, S.B. Dorofeev, W. Breitung

8:55 Modelling of Premixed Turbulent Combustion with Variable Equivalence Ratio using a New << partial pdfs >> Approach (#45)
Arnaud Mura, Francois Xavier Demoulin, Roland Borghi

9:20 Modeling of Extinction and Re-ignition in Non-premixed Turbulent Combustion (#195)
Heinz Pitsch, Chong Cha, Sergei Fedotov

9:45 Modelling Of Turbulent Jet Flames (#176)
T.J. Craft, Y. Zhang, W.T. Chan

10:30 AM **KANE 210**

PULSE DETONATION II

Session Chairs: G. Roy and D. Desbordes

10:30 Detonation Propagation in Variable Cross Section Channels (#108)
Toshi Fujiwara, Ayumi Takasu, Takeshi Miyasaka

10:55 Pulse Detonation Engine on Gasoline - Air Mixture (#102)
D.I. Baklanov, L.G. Gvozdeva, N.B. Scherbak

11:20 MEMS-Based Pulse Detonation Engines for Small-Scale Propulsion Applications (#73)
Edward Furlong, Ivett A. Leyva, Simon Sanderson

11:45 Effect of Transient Gas Dynamic Processes on Impulse of Pulse Detonation Engines (#155)
V. Tanguay, C.B. Kiyanda, A.J. Higgins, J.H.S. Lee

12:10 On the Exit Boundary Condition for One-dimensional Calculations of Pulsed Detonation Engine Performance (#182)
Jack Wilson, Daniel E. Paxson

10:30 AM **KANE 220**

LAMINAR FLAMES II

Session Chairs: R. Baron and N. Peters

10:30 Investigation Singing into Conditions Enabling the Excitation of the Kinetic Flame (#101)
Vladimir V. Afanasyev, Stanislav V. Ilyin, Nikolai I. Kidin, Nikolai A. Tarasov

10:55 Buoyancy Effect on Stable and Oscillating Flames in Coflow Jets for Highly Diluted Propane (#70)
Junhong Kim, Moo Kyung Shin, Suk Ho Chung

11:20 Non-Adiabatic Strained Premixed Flames — the Effect of Sudden Transient Cooling by a Pressure Drop (#35)
Andy C. McIntosh, John Brindley, Xin-She Yang

11:45 A Singular-Perturbation Analysis of the Burning-Rate Eigenvalue for a Two-Temperature Model of Deflagrations in Confined Porous Energetic Materials (#9)
Stephen B. Margolis, Melvin R. Baer

10:30 AM — **KANE 120**

NON-PREMIXED TURBULENT FLAMES III

Session Chairs: F. Williams and J. Furukawa

10:30 Heat Release Effects in Lifted Laminar Jet Diffusion Flames (#44)
Joan Boulanger, Sandip Ghosal, Julien Reveillon, Luc Vervisch

10:55 Experimental Studies on Flame Stabilization and NOx/Noise Reduction in Lifted Hydrogen-Jet Flames (#170)
Yasuo Yamazaki, Michio Haba, Takasi Endo, Noyuki Himi, A.Koichi Hayashi, Robert K.Cheng

11:20 Raman Measurements of the Stabilization Process of a Lifted Flame Tuned by Acoustic Excitation (#74)
Yei-Chin Chao, Chih-Yung Wu, Tony Yuan, Tsarng-Sheng Cheng

11:45 Characterization of Non-premixed Hydrogen-oxygen Flame Heights by Chemical Luminescence Imaging and LDV Techniques (#144)
J-L. Beduneau, D. Honore, M.A. Boukhalfa

12:10 Identification of the Transfer Function in a Model Gas Turbine Combustor: Application to Active Control of Combustion Instabilities (#47)
Daniel Bernier, Sebastien Ducruix, Francois Lacas, Sebastien Candel, N. Robart, T. Poinsot

2:00 PM — **KANE 210**

PULSE DETONATION III

Session Chairs: C. Brophy and S. Zhdan

2:00 Use of Thermochemical Conversion in Pulse Detonation Engine (#60)
D.I. Baklanov, V.V. Golub, O.G. Divakov, A.V. Eremin

2:25 Combustible Mixture Injection and Ignition in Downstream of 2-D Detonation (#106)
Toshi Fujiwara, Soshi Kawai, Takeshi Miyasaka

2:00 PM — **KANE 120**

VALIDATION OF REDUCTION PROCEDURES

Session Chair: S. Margolis

2:00 Validation of Selection Parameters for Steady State Species for Automatic Reduction of Chemical Mechanisms (#175)
Terese Løvås, Daniel Nilsson, Fabian Mauss

2:25 Validation of a New Chemistry Reduction Method for Partially-Premixed Laminar Methane/Air Flames (#18)
Olivier Gicquel , Dominique Thevenin , Nasser Darabiha

2:00 PM — **KANE 220**

LAMINAR FLAMES III

Session Chairs: P. Lindstedt and S. Shy

2:00 Computational and Experimental Study of Ammonium Perchlorate Counterflow Diffusion Flames (#151)
Mitchell D. Smooke, Richard A. Yetter, Timothy P. Parr, Donna M. Hanson-Parr

2:25 Experimental Study of Low Reynolds Number Reacting Flows: Gas-gas Laminar Flat Plate Diffusion Flame in Microgravity (#42)
Pierre Cordeiro, Pierre Joulain, José L. Torero

2:50 PM — **WALKER AMES ROOM**

POSTER SESSION II

P1 Turbulent Combustion of Sprays (#230)
H.H. Chiu

P2 Modeling and Control of Mixing in a Transverse Jet (#223)
Youssef M. Marzouk, Ahmed F. Ghoniem

P3 Model Studies of Fuel Injection (#216)
Wieslaw Glinka , Zbigniew Gut , Eugeniusz Budny , Janusz Przastek

P4 Simulation of Combustion of Supersonic Hydrogen Jets in a Supersonic Air Flow (#71)
Sh.A. Ershin, U.K.Zhapbaspayev, A.Kaltayev, T. Fujiwara

P5 Probe Method of Sampling of Combustion Products of Solid Rocket Propellant at Temperatures and Pressures Typical of Combustion Chamber of Rocket Motor (#82)
O.P. Korobeinichev, A.G. Tereshenko, P.A. Skovorodko, A.A. Paletsky, E.N. Volkov

P6 Numerical Simulation of Dust Layer Dispersion Due to Rarefaction Waves (#100)
Rudolf Klemens, Pawel Kosinski

P7 Modeling of CO Formation in Turbulent Premixed Combustion (#160)
Per Nilsson, Xue-Song Bai

P8 Calculation of Deflagrating Flame in a Rectangular Duct with Internal Solid Obstruction (#21)
S.S. Ibrahim, S.N.D.H. Patel, G.K. Hargarve

P9 Analysis of the Critical Conditions of Ignition of Gas-suspended Solid Fuel with a Heated Surface (#219)
Boris S. Seplyarskii, Tatyana P. Ivleva

P10 Gas and Coal Dust Combustion with Staged Air and Pulsation Effect (#58)
Lech Szecowka, Henryk Radomiak

P11 Combustion Mechanism of the Multi-way Impinging-type Burners (#197)
Jing-Tang Yang, Han-Chang Cheng, Fu-Ane Chen, Shiung-Fu Chen

P12 Inverse Methods In Interior Ballistics Processes Study (#222)
Vladimir Arkhipov, Evgeny A. Zverev, Dmitry A. Zimin

P13 Radiative Properties of Water Vapor by Optical Study of Hydrogen-air Combustion (#229)
Pascale Chelin, Vincent Pina, Philippe Hervé

P14 Turbulent Combustion in Cellular Detonations (#67)
A. Efimenko, S. Dorofeev

P15 Theoretical Study of Shock Wave Ignition of Aluminum Particles (#5)
Tao Hong

P16 On Modeling of Electrochemical Detonation Pulsejet (#29)
V.Korobeinikov, V.Markov, I.Semenov, S.Wojcicki

P17 Influence of Small Additives of Xe on Detonation Threshold of a Mixture of O2. H2 and He (#57)
Serguei Koulikov, Georguei Manelis

P18 Initiation of Detonation in Confined Volume by Converging Shock Wave (#25)
V.Levin, V.Markov, S.Osinkin, T.Zhuravskaya

P19 Spark Ignition in the Pre-Heated CH4-Air Mixtures Behind Reflected Shock Waves (#203)
Alexaner B. Britan, Gregory Pilch, Eran Sher, A. Yu Starikovskii

P20 Spontaneous Detonation in the Mixture of Initial Reagents with Hot Detonation Products (#103)
V.I. Tarzhanov, I.V. Telichko, V.G. Vildanov, V.I. Sdobnov

3:40 PM ***KANE 210***

PULSE DETONATION IV

Session Chairs: C. Brophy and S. Zhdan

3:40 JP-10 Vapour Detonations at Elevated Pressures and Temperatures (#20)
Fan Zhang, Stephen B Murray, K. Gerrard

4:05 Electric-Discharge Control of Pre-Detonation Processes (#97)
Vladimir V. Afanasyev, Stanislav V. Ilyin, Aleksei V. Lapin, Nikolai I. Kidin

3:40 PM — **KANE 220**

SWIRLING AND ENCLOSED FLAMES

Session Chairs: C. Correa and S. Ducruix

3:40 Extinction Mechanism of Swirling Lean Methane-Air Flames (#53)
Kazufumi Yorimori, Makihito Nishioka, Tadao Takeno, K.N.C. Bray

4:05 Influence of Tube Dimensions on Flame Behavior near Lean Flammability Limits (#167)
Jozef Jarosinski, Artur Gutkowski

4:30 The Dynamic Behaviour of Turbulent, Premixed Swirl Flames (#173)
Christian Külsheimer, Horst Büchner, Henning Bockhorn

3:40 PM — **KANE 120**

SOOT AND FULLERENES IN TURBULENT FLAMES

Session Chair: M. Smooke

3:40 Dynamics of Solid Carbon Formation by Turbulent Combustion and Thermal Decomposition of Natural Gas (#68)
Thomas M.Gruenberger, Mohammad Moghiman, Phil J. Bowen, Nick Syred

4:05 Numerical Investigation of Combustion and Soot Formation Processes in Turbulent Nonpremixed Flame (#84)
Hoo-Joong Kim, Yong-Mo Kim

4:30 Hydrocarbon Combustion: A Better Technique for Large Scale Production of Fullerenes (#88)
Mohamed Hammida, Antonio Fonseca, Paul A.Thiry, Janos B.Nagy

8:30 AM — **KANE 210**

RAMAC I

Session Chairs: A. Bruckner and C. Li

8:30 Ram Accelerator Operation at 15 to 20 MPa Fill Pressure (#184)
Christopher Bundy, Carl Knowlen, Adam P. Bruckner

8:55 Compressibility Effects of Unreacted Propellant on Thermally Choked Ram Accelerator Performance (#168)
P. Bauer, C. Knowlen, C. Bundy, A.P. Bruckner

9:20 Effect of a Suspension of Magnesium Particles on the Detonation Characteristics of Methane-Oxygen-Nitrogen Mixtures at Elevated Initial Pressures (#112)
Bernard Veyssiere, Olivier Bozier, Boris Khasainov

9:45 Visualization of Burning Flow Around the Projectile in Ram Accelerator by Coaxial Simultaneous Shadow/Direct Photograph (#145)
Tomoaki Yatsufusa, Shiro Taki

8:30 AM — **KANE 220**

LAMINAR FLAMES IV

Session Chair: F. Baillot

8:30 Reattachment of Lifted Flames in Laminar Propane Jets (#69)
Jongsoo Lee, Suk Ho Chung

8:55 Surface Instability and Droplet Pinch-Off for Liquid Films and Filaments (#109)
Dirk Meinköhn

9:20 Three-dimensional Ignition and Flame Propagation Above Liquid-Fuel Pools: Computational Analysis (#122)
J. Cai, F. Liu, W.A. Sirignano

8:30 AM — **KANE 120**

TURBULENT SPRAY AND JET FLAMES I

Session Chairs: S. Dorofeev and K. Yorimori

8:30 Turbulence and Velocity Induced by Combusting Impinging Jets (#177)
G.M. Abu-Orf, Y. Zhang, B.E. Launder, K.N.C. Bray

8:55 Local Extinction and Reignition in Nonpremixed Turbulent Jet Flames: A View Using the One-Dimensional Turbulence Model (#192)
John C. Hewson, Alan R. Kerstein, J.H. Chen

9:20 Assessing the Risk of Spontaneous Ignition of Coal and Biomass (#199)
Y.S. Nugroho, A.C. McIntosh, B.M. Gibbs

10:30 AM *KANE 210*

RAMAC II

Session Chairs: A. Bruckner and C. Li

10:30 Investigation of the Ram Accelerator Projectile In-tube Stability (#193)
Liu Sen, Bai Zhiyong, Carl Knowlen, Adam P. Bruckner

10:55 Numerical Study of the Effect of Shock Strength on the Normal Start and Unstart Process in a Superdetonative Mode Ram Accelerator (#76)
Guee-Won Moon, In-Seuck Jeung, Jeong-Yeol Choi, Friedrich Seiler, Gunther Patz, Gunter Smeets, Julio Srulijes

11:20 Dynamics of Laser-Driven Blast Wave Generated in Space Propulsion Configuration (#16)
Akihiro Sasoh

11:45 Critical Condition for Stabilized Chapman-Jouguet Oblique Detonation Waves Around Hypersonic Bodies (#198)
Jiro Kasahara, Takakage Arai, Akiko Matsuo, Nobutaka Akai, Kouki Takazawa

12:10 Ram-Acceleration Enhancement through Projectile and Staging Design (#95)
Yuichiro Hamate, Akihiro Sasoh, Kazuyoshi Takayama

10:30 AM *KANE 220*

FLAME INTERACTIONS / EXPLOSIONS

Session Chairs: Y. Yamazaki and P. Kosinski

10:30 Scale Effect on Recirculation Zone of the Bluff-body Burner with Concentric Jets (#150)
Jing-Tang Yang, Yu-Ping Kang

10:55 Structural Characteristics and NOx Formation in an Oscillating Stagnation Flat Flame (#208)
Yei-Chin Chao, Yau-Wei Huang, Guan-Ban Chen

11:20 Dynamic Response of a Non-Premixed Flame to Electric Field Forcing (#141)
Ben A. Strayer, Derek Dunn-Rankin

11:45 Quenching Distance Measurement for the Control of Hydrogen Explosion (#191)
Hong Jip Kim, Seong Wan Hong, H.D. Kim, Seung Yeon Yang, Suk Ho Chung

12:10 Dust-Air Mixtures Spreading in Branched Ducts (#99)
Rudolf Klemens, Pawel Kosinski, Piotr Wolanski, Victor Korobeinikov, V.V. Markov, I.S. Menshov

10:30 AM — KANE 120

NEW DEVICES AND METHODS

Session Chair: T. Gruenberger

10:30 The Application of Spontaneous Vibrational Raman Scattering for Temperature Measurements in High Pressure Laminar Flames (#15)
T. S. Cheng, T. Yuan, C.-C. Lu, Y.-C. Chao

10:55 Appropriate Use and Basic Characteristics of Electrostatic Probes (#81)
Toshisuke Hirano, Junichi Furukawa

11:20 NO- and HC- Removal by Non-Thermal Plasmas (#86)
I. Orlandini, U. Riedel

11:45 Hydrogen Oxidation and Ignition Development by Nanosecond High-Current Discharge (#205)
D.V. Zatsepin, S.M. Starikovskaia, Andrei Yu. Starikovskii

12:10 Laminar-to-Turbulent Flame Transition Initiated by Generation of Instabilities in an Ignition Kernel (#30)
Eugene Gordon, Yurii Moskvin, Vladislav Zelenov, Alexander Shteinberg

2:00 PM — KANE 210

HETEROGENEOUS COMBUSTION

Session Chair: B. Veyssiere

2:00 Combustion of Supersonic Metallic Spheres (#125)
A.J. Higgins, D.L. Frost, C. Knowlen, F. Zhang, S.B. Murray

2:25 Formation and Thermal Decomposition of Solid Carbon Particles during Pyrolysis of Carbon Suboxide behind Shock Waves (#227)
G.L. Agafonov, M. Nullmeier, P.A. Vlasov, J. Warnatz, I.S. Zaslonko

2:00 PM — KANE 220

SECONDARY COMBUSTION

Session Chair: S. Frolov

2:00 Promotion of Secondary Combustion Phenomena by Geometrical Constrains in the Course of Non-Ideal Explosions (#56)
B.E. Gelfand, A.M. Bartenev, L.H. Josephson, M. Banks, S.V. Khomik, S.P. Medvedev, A.N. Polenov, P. Williams

2:25 Optical Temperature Diagnostics of After-Burning Phenomena in Expanded HE Detonation Products (#89)
B.E. Gelfand, M.F. Gogulya, S.P. Medvedev, A.N. Polenov, S..V. Khomik, A.M. Bartenev

2:50 Mixture of Initial Reagents with Hot Detonation Products as the Subject of Studies in the Shock Tube (#80)
V.I.Tarzhanov

2:00 PM — **KANE 120**

MULTIPHASE COMBUSTION II

Session Chairs: I. Goldfarb and I. Altman

2:00 Flame Spread over Thermally Thin Layer System "Metallic Substrate – Fuel Film" (#133)
A.A. Korzhavin, V.A. Bunev, S.S. Minaev, I.G. Namyatov, V.S. Babkin

2:25 Partially Premixed Combustion in Spray Flames (#115)
J. Reveillon, L. Vervisch

2:50 Delayed Thermal Explosion in Inert Porous Matrix Filled with Evaporating Liquid Fuel (#169)
I. Goldfarb, V. Gol'dshtein, A. Zinoviev

3:40 PM — **KANE 210**

DETONATION HAZARD

3:40 Hydrocarbon Gas Hydrates and Their Detonation Hazard (#4)
A.A.Vasil'ev, A.I.Valishev, V.A.Vasil'ev, L.V.Panfilova

4:05 Ignition of Liquid and Dust Fuel Layer by Hydrogen-Oxygen Detonation (#233)
Piotr Wolanski, Arkadiusz Kobiera

3:40 PM — **KANE 220**

NUMERICAL COMPUTATIONS

Session Chairs: A. Cohen and D. Bradley

3:40 Fast and Accurate Flame Computations Using Detailed Chemistry and Transport (#36)
Romain Baron, Sebastien Paxion, Dominique Thévenin

4:05 Numerical Simulation of Compressible Reactive Viscous Flow in Complex Geometries (#196)
Marcello Manna, Francesco S. Marra, Andrea Pascarelli

3:40 PM — **KANE 120**

TRANSONIC AND SUPERSONIC COMBUSTION

Session Chair: TBA

3:40 Combustion in a Transonic Flow with Large Axial and Transverse Pressure Gradients (#128)
Jingshen Cai, Olgu Icoz, Feng Liu, William A. Sirignano

4:05 Stability of Underexpanded Supersonic Jet Flames Burning H2-CO Mixtures (#48)
C.B. Devaud, J.B. Kelman, J.B.Moss, C.D. Stewart

Cellular Structure I

Abstract #159

On the Origin of the Double Cellular Structure of Detonation in Gaseous Nitromethane

N. Lamoureux, C. Matignon, M.-O. Sturtzer, D. Desbordes, H.-N. Presles

An experimental study of the detonation in pure gaseous nitromethane (NM) or mixed with oxygen has exhibited unambiguously the existence of a double cellular structure in the range of equivalence ratio F from 1.3 to 1.75 (pure NM). Calculations of the reaction zone of the detonation in the same range of equivalence ratio, using a detailed chemical kinetics scheme in the ZND frame, demonstrate that the chemical energy is released in two main successive reaction steps characterized by their own induction length. This work shows that these two main exothermic reaction steps, through their induction length, justify the two levels of cellular structure. To our knowledge, this work is the first which deals with the problem of non monotonous chemical energy release behind the leading shock of a detonation wave. Results obtained strengthen the idea that the cellular detonation structure find its origin in instabilities amplified by the high energy release rate inside the reaction zone.

Abstract #79

A Numerical Study of Hydrogen/Air Detonation Using a Pressure Dependent Stanford Model: Formation and Burning of Unreacted Gas Pocket

Nobuyuki Tsuboi, Hiroshi Shimizu, A.Koichi Hayashi, Yoichiro Matsumoto

Two-dimensional numerical simulation for H2/Air detonation was performed by using a pressure dependent Stanford model. The governing equations are made from the Euler equations with the mass conservation of 9 species and with 18 elementary reactions. The equations are explicitly integrated by second-order Strang type fractional step method. The source terms with chemical reaction are treated in a linearly point-implicit manner. As for a numerical flux scheme, Harten-Yee non-MUSCL type TVD scheme is used. The Stanford model has 9 species and 18 elementary reactions with pressure dependence. The model includes H2O2 and HO2 chemistry near the second and third explosion limit, which is necessary for ignition at ram accelerator pressures but lacking in certain finite chemistry models currently in use. The rate coefficients for H2O2 and HO2 reactions has a pressure dependent rate coefficient defined by method of Troe. The results showed that the detailed mechanisms of the formation and the explosion of the unreacted pocket was revealed clearly and that the isolated unreacted pocket were ignited from its rear side by the intersection of the transverse shock. The maximum pressure history and the local specific energy release history showed that the transverse shock intersection and the explosion of the

unreacted pocket cause the weak longitudinal and transverse tracks.

Abstract #207

Numerical Investigation of Transverse Wave Structures in Two-Dimensional H2-O2-Diluent Detonations

Kazuaki Inaba, Akiko Matsuo, Katsumi Tanaka

Two-dimensional computations of the propagating detonations in the mixture of 2H2+O2+3.76N2/3.76Ar at initial pressures 1.00, 0.421, and 0.132 atm were performed using a detailed chemical reaction mechanism. The transverse wave strength was defined as the dimensionless pressure increase across the reflected shock and was determined for the different channel widths. When a detonation propagates through a narrow channel in all cases, the shock structure evolves from a single Mach structure to a double Mach structure. In H2-Air at 1.00 and 0.421 atm, the transverse wave strength increases up to 1.5 with increasing the channel width, and the shock configuration evolves from the single Mach structure to a complex Mach structure. Both in H2-Air at 0.132 atm and H2-O2-Ar at 1.00 atm, the transverse wave strength does not go beyond 0.85, but the flow features show the complex Mach structure. In H2-O2-Ar at 0.132 atm, the transverse wave evolves up to the double Mach structure and the transverse wave strength indicated 0.5. Although the complex Mach structure appears, except for the case of H2-O2-Ar at 0.132 atm, the strong transverse detonations occurs only in H2-Air at 1.00 and 0.421 atm. We pursuit the lowest post-shock pressure and temperature and recognize that only the conditions of H2-Air at 1.00 and 0.421 atm varies across the second explosion limit. Therefore we summarize that the strong transverse detonation occurs due to the change in post-shock properties, which results in the immediately increase of the induction length and the onset of the strong transverse detonation.

Explosion Physics

Abstract #8

Pressure Diagnostics of Combustion Following an Explosion

A.K. Oppenheim, T-H Sum

The problem is concened with a rational interpretation of the thermodynamic and fluid dynamic phenomena taking place in a closed vessel upon detonation of an explosive charge and subsequent turbulent combustion of its products,acting as fuel for an exothermic reaction with the shock compressed air. The paper presents the chemical and thermodynamic background and its numerical results, deduced for this purpose from mass spectroscopic data and pressure records, acquired upon explosion of a 0.8 charge of TNT in a 17 m3 chamber filled with air. The evolution of the flow field will be presented by movies of its fluid dynamic phenomena, computed on this basis.

Abstract #188

Mixing-Controlled Exothermic Fields in Explosions

A.L. Kuhl, R. Ferguson

A theoretical model of combustion in explosions at large Reynolds, Peclet and Damköhler numbers is described. A key feature of the model is that combustion is treated as material transformations in the Le Chatelier state plane, rather than "heat release". In the limit considered here, combustion is concentrated on thin exothermic sheets (boundaries between fuel and oxidizer). The products seem to expand along the sheet, thereby inducing vorticity that continues to feed the process. The results illustrate the linking between turbulence (vorticity) and exothermicity (dilatation) in the limit of fast chemistry-thereby demonstrating the controlling role that fluid dynamics plays in such problems.

Abstract #62

Explosion-Induced Combustion of Hydrocarbon Clouds in a Chamber

Peter Neuwald, Heinz Reichenbach, Allen L. Kuhl

The interaction of the blast wave from the detonation of a solid HE-charge with a non-premixed cloud of hydro-carbon fuel in a chamber was studied in a series of laboratory experiments. Soap bubbles filled with a flammable gas such as butane were subjected to the detonation of PETN-charges with a mass ranging from 0.2 to 0.5 g. The dynamics of the system were investigated by means of high-speed photography and measurement of the quasi-static chamber pressure. The combustion-induced increase of the quasi-static pressure indicates that ignition probability and the burning rate depend on charge mass and position. These also influence the flow dynamics in the chamber. In the investigated parameter range the combustion processes thus appear to be dominated by the flow dynamics and especially the turbulence.

Premixed Turbulent Flames I

Abstract #40

Surface Density Measurements for Freely-Propagating Premixed Turbulent Flames at Various Lewis Numbers

B. Renou, A. Mura, E. Samson, A. Boukhalfa

The flame surface density for non-stationary premixed turbulent flames is measured for different fuel/air mixtures (methane, propane and hydrogen/air) in order to evaluate the influence of the Lewis number. These mixtures are separately spark-ignited in a vertical wind tunnel. The expanding flame freely propagates in a grid-generated decaying isotropic turbulent flow. Two-dimensional laser sheet tomography technique is used to characterize the instantaneous flame front position, from ignition to fully development stages. The flame surface density evolution is obtained from the conditional gradient of the progress variable with 150 flames for each propagation time. The global profiles of the flame surface density are symmetrical about a peak value and globally present

a parabolic trend. The maximum of flame surface density decreases as the flame propagates. The evolutions of this maximum are identical for all the Lewis number used in this experimental work, for two levels of turbulence. This result indicates that the effect of the Lewis number on the flame surface density, as observed in these experimental results, is primarily an effect on turbulent flame thickness. The maximum flame surface density presents also a slight influence with u'/SL, for the three fuel/air mixtures. For each propagation time, the maximum of fame surface density decreases for an increasing of the turbulence level u'/SL (at constant laminar flame speed SL), whatever the variation of the integral length scale. These results are then discussed and compared with previous experimental and numerical data available in the literature.

Abstract #161

Direct Numerical Simulation of a Statistically Stationary Turbulent Premixed Flame

Raphael Hauguel, Pascale Domingo, Julien Réveillon, Laurent Guichard-Vervisch

A new numerical procedure has been used to performed direct numerical simulation of a stabilized premixed flame in a spatially decaying turbulence. This method has been developed for fully compressible subsonic flows. Attention is confined to premixed turbulent combustion in the laminar flamelet regime. In these circumstances, reacting flow models can be tested for all pressure fluctuation covariances that are known to play a crucial role in the second moment closure of the averaged equations of turbulents flows. Models, which are applicable to the thin laminar flamelet regime of premixed combustion, are based on the BML formalism. Direct numerical simulation of the premixed flame is then used to assess the validity of models. Good agreement is found between the model expressions and pressure fluctuation covariances evaluated from DNS.

Abstract #139

Heat Loss Rates from Hydrogen-Air Turbulent Flames in Tubes

M. Kuznetsov, I. Matsukov, S. Dorofeev

Experimental study of heat losses from turbulent combustion processes in obstructed tubes is presented. Tests are made with hydrogen-air mixtures in tubes with internal diameter of 174 mm and 520 mm. Direct measurements of heat flux to tube walls versus time during flame propagation are conducted. It is shown that total energy absorbed by tube walls is equivalent to the mixture chemical energy for all the mixtures tested. The rate of energy losses from combustion processes depends significantly on the speed of the flame propagation. The average heat flux, q(0.5), at the time of half-energy release is used to characterize the intensity of heat losses. The value of q(0.5) increases from 10 to about 80 W/sq.cm with increase of turbulent flame speed from 10 to 800 m/s. It is shown that tube diameter does not influence significantly the characteristic

values of heat fluxes, while the characteristic duration of energy losses as well as total energy absorbed differ greatly in two tubes. This observation indicates that the main mechanism for heat losses under the conditions of present tests is convective heat transfer. This conclusion is supported by comparison of overall rate of heat losses with the measurements of its radiant component. The results suggest that qualitative and quantitative account for heat losses from combustion products is necessary to be included in turbulent combustion models to increase reliability of their predictions.

Plenary Lecture I

Abstract #P1

Problems of Predicting Turbulent Burning Rates

Derek Bradley

At present there are two main approaches to the understanding and mathematical modelling of practical turbulent combustion. These involve the joint probability density function (JPDF) transport equations [1,2] and laminar flamelets [3,4]. There is no conflict in the way the complexities of turbulent-reaction interactions are handled, but each approach emphasises different aspects and the computational requirements are different. The JPDF approach is capable of exactly representing the interaction of chemical reactions and convection, although viscous dissipation and turbulent mixing of scalars must be closed by modelling. The computational demands of detailed chemistry can be excessive, but these diminish with intrinsic low-dimensional manifolds (ILDM) [5] that reduce the chemistry from that of a fully detailed scheme. The in situ adaptive tabulation, ISAT, algorithm [6] also reduces the computational effort. Direct numerical simulations (DNS) [7] are valuable in suggesting closure procedures in moment methods, while large eddy simulations (LES) [8] give a more realistic picture of practical flows than do first and second moment models. Laminar flamelet methods computationally uncouple the chemistry from the turbulence in stretched laminar flame studies then re-couple it in the turbulent flame. The conditional moment closure (CMC) approach [9] has affinities with flamelet methods. With CMC in non-premixtures most of the scalar fluctuation can be associated with the mixture fraction, and conditional averaging with respect to it allows closure of the conditional average chemical reaction term. Normally these conditional fluctuations of the reactive scalars are smaller than the unconditional fluctuations and can be neglected. If they are not, conditioning of second moments might be employed. The laminar flamelet approach has proved rather more robust and effective than might originally have been anticipated. One reason, revealed by direct numerical simulations, is that a continuous laminar flame structure can be thickened by small scale turbulence without invalidating the flamelet assumption [7,10]. As a result, a Karlovitz flame stretch factor can be accommodated which is 17 times that of the Klimov-Williams limit [11]. The principal

parameters that express burning rate are the turbulent burning velocity and the mean volumetric heat release rate. The burning velocity is rather difficult either to define precisely or to measure rigorously. It is not a convenient parameter when there is no readily discernible propagating flame front, as in furnaces and gas turbine combustion chambers with recirculating flow, or when the front is severely disrupted at high Karlovitz stretch factors. Under such conditions, the mean volumetric heat release rate is a more convenient parameter and computation of its spatial distribution can be readily incorporated into CFD codes. The paper attempts a unified approach, that embraces both of these parameters, and highlights some current problems. A new expression is presented for the turbulent burning velocity, based on a universal pdf of turbulent strain rates, with both flamelet burning and quenching controlled by Markstein numbers, and some fractal considerations. Different expressions for the turbulent burning velocity are compared.

Cellular Structure II

Abstract #13

Interaction between Shock and Detonation Waves

Kunio Terao, Takayuki Yoshida, Kazuaki Kishi, Kazuhiro Ishii

Detonation waves propagating in a stoichiometric propane-oxygen mixture at the collision with shock waves are investigated, by observation of their propagation velocity and cellular structure recorded on a soot film. The experimental results suggest that the propagation velocity increases after the shock collision, while the Mach number decreases, and the cellular pattern becomes finer. The probability of apex formation in the cellular structure depends on the temperature and density of the mixture behind the shock waves at the detonation front. The apex formation probability is moreover equal to the probability of spontaneous ignition in the same mixture under the same condition. It is thus concluded that the cellular structure is formed by the spontaneous ignition and the gas flow behind the shock waves at the detonation front.

Abstract #201

Measurement of Surface Pressure with Pressure Sensitive Paint in a Detonation Tube

Yukihiro Sukawa, Koichi Hayashi

Pressure sensitive paint will be used in a detonation tube to measure a surface pressure of the detonation wave and make a visualization to see its structure. A conventional method to see detonation structure is with a pressure transducer or a smoked foil. The method was available to roughly measurement and observation, not detail. The pressure sensitive paint technique is developed and used mainly in aerodynamics recently and this technique will be also useful for combustion and other phenomenon.

Abstract #23

Cellular Structure of Spray Detonation

S.A. Zhdan, E.S. Prokhorov

On the basis of the mathematical model of a two-phase two-velocity medium, detonation of a cryogenic (80 K) mixture (gaseous hydrogen-drops of liquid oxygen) was studied numerically. Transverse instability of two-dimensional reaction zone of heterogeneous detonation wave (DW) was obtained in the form of cellular structures with cell size depending on the droplet diameter. It was found that the heterogeneous DW reaches a periodic regime with a regular cellular structure only for certain discrete values of the channel width (eigenvalues of the problem). The special features of dynamics of the transverse wave and gas-dynamic parameters in the reaction zone during oneperiod are analyzed. The cell size is calculated, which increases almost linearly with increasing initial diameter of oxygen droplets.

Gas Explosions

Abstract #148

Review of Contributions of Fraunhofer ICT to Gas Explosion Research - Illustrated by Film Documents

Helmut Schneider, Gesa Langer, Norbert Eisenreich, Wolfgang Liehmann

Fraunhofer Institut für Chemische Technologie (ICT) has been active in the field of gas explosions during the last 25 years. Quite a lot of experiments predominantly on a medium and on a large scale have been performed - some of which with fundamental importance for the understanding of gas explosions. The intention of this paper is to present a review of selected results of our investigations achieved under the management of the late Dr Pförtner: detonation and deflagration of premixed fuel/air mixtures of different gases; the influence of turbulence, obstacles, cloud shape, ignition mode and ignition location on flame speeds and overpressures; combustion of flash evaporated, non-premixed fuel/air mixtures; and conditions for deflagration to detonation transition. We think that the presentation is especially attractive because we intend to use film material recorded during the tests for measuring the propagation of flames and of detonation fronts. Thus the topic will probably be better understood - apart from the fact, that the pictures are very impressive.

Abstract #164

Time Resolved Flow Characteristics of Confined Turbulent Gaseous Explosions

R.P. Lindstedt, H.A. McCann

The transition of a turbulent flame to a gaseous explosion in a confined pre-existing turbulent flow field is of direct scientific and practical interest. Related topics include the intentional transition to detonation in pulsed detonation engines and industrial hazard assessment. Experimental data sets suitable for the developments of predictive techniques are required in order

to advance the basic understanding of such flows. The present paper thus outlines an experimental study into the interactions between baffle accelerated premixed turbulent flames and their self-generated flow in a long closed flame tube. In particular, the effects of a pre-existing velocity field at the ignition point located upstream of the baffle are examined. Flow characteristics, including time-resolved mean and rms profiles in a two-dimensional plane, have been obtained using laser Doppler anemometry for a stoichiometric methane-air flame. Instantaneous spark schlieren photographs have been obtained around the baffle to elucidate the flame behaviour and qualitatively describe the burning process. The present configuration yields over-pressures of around 200 kPa and peak mean velocities around 150 m/s — both significantly higher than those reported by Lindstedt & Sakthitharan (1998) for initially quiescent mixtures.

Abstract #189

Characterisation of Confined Turbulent Gas Explosions with Reference to Protection Methodologies

C.L. Gardner, H.N. Phylaktou, G.E. Andrews

The application of empirical equations based on Kg values, recommended for gas explosion protection design, are limited to near zero turbulence conditions. In this study, we report explosion tests with methane, ethylene and hydrogen mixtures with air, under variable turbulence conditions in a standard ISO 1m3 vessel. The measured flame speeds, Kg values, and derived turbulent burning velocities are correlated to the levels of turbulence in the vessel, on the basis of published turbulence decay models for identical vessels. Linear dependence of the above parameters on u' is obtained in agreement with other published work, but it is shown that the quantitative correlations reported here and in the literature are wide ranging (in terms of the proportionality constants) and may not be applicable in a quantitative sense to any other system.

Premixed Turbulent Flames II

Abstract #12

On Accuracy of the Turbulent Burning Velocity Measured in a Cruciform Burner using Ion-Probe Sensors

W.J. Lin, R.C. Su, S.S. Shy

We have measured turbulent burning velocities of methane-air and propane-air mixtures over a wide range of equivalence ratios and turbulent intensities (u'/SL) up to 50 using a pair of ion-probe sensors. These results were compared with other experimental data using different burners and they can be fitted into a general correlation of the form (ST-SL)/u'=0.05 Da^0.61, where Da is the Damkohler number. This correlation is found to be better than previous correlations, which covers both corrugated flamelet (large Da) and distributed (small Da) regimes. However, some questions remain to be answered. Do the ion-probe sensors actually measure the turbulent burning velocity (not the turbulent flame speed)? In other words, can

the gas velocities ahead of propagating turbulent flames be neglected? What are the effects of pressure rise due to turbulent burning in the cruciform burner on ST measurements? This work addresses these questions and validates the accuracy of our ST measurements using two ion-probe sensors.

Abstract #46

Simulations of Premixed Turbulent Stagnation Flames with a Flame Speed Closure Model

Andrei N. Lipatnikov, Jerzy Chomiak

Numerical simulations of premixed turbulent stagnation flames have been performed using the Flame Speed Closure (FSC) model in order: (1) to further test the model under inauspicious conditions, and (2) to test whether or not stagnation flames are equivalent to fully developed flames in homogeneous flow fields, i.e., to planar flames of a constant thickness, which propagate at a constant speed against a stationary and spatially uniform unburned mixture flow. Numerical simulations of various known experiments have been performed without variations in the only remaining model constant. The results indicate that the model well predicts the stationarity of these flames, their structure, their mean thickness, and the local minimum of the mean gas flow velocity, associated often with turbulent flame speed. The ability of the model to predict the above properties suggests that the flames studied are not fully developed, because the FSC model cannot describe the aforementioned classical fully developed flames, in principle. A simple model problem described semi-analytically is considered in order to show possible difference between premixed turbulent stagnation flames and the classical fully developed ones.

Abstract #162

Some Aspects on Level-set Modelling of Premixed Turbulent Combustion

Per Nilsson, Xue-Song Bai

A level-set flamelet library approach is investigated, especially in terms of the level-set flame position tracking formulation. Different methods for the numerical propagation of a distance function, denoting the distance to the mean flame surface, have been tested. One of them, the Fast Marching Method with extension velocities has shown beneficial thanks to the extension velocity algorithm. The mean turbulent flame is assumed to be an ensemble of locally laminar flamelets fluctuating around a mean flame position. Each flamelet has its own local structure of temperature and species as a function of the flamelet coordinate. This structure is simulated in a laminar flame calculation and stored in a table, called a flamelet library. The G-equation is employed to trace the mean flame surface, and a presumed Gaussian distribution of position around the surface is employed to average the locally laminar flamelet properties over the turbulent flame. The turbulent flow modelling frame work is that of standard k-epsilon and the

computational field is discretized using Finite Differences on a staggered Cartesian grid. Measurements from the VAC Validation Rig 1, in which lean premixed propane/air V-shaped flame is stabilised behind a triangular prismatic flame holder in a rectangular channel, are utilised for some assessment of the simulated data.

Detonation Structure

Abstract #137

Direct Observations of Reaction Zone Structure in Propagating Detonations

F. Pintgen, C. Eckett, J. Austin, J.E. Shepherd

We report experimental observations on the reaction zone structure of self-sustaining, "cellular" detonations propagating near the CJ state in hydrogen-oxygen-argon mixtures. Two-dimensional crosssections perpendicular to the propagation direction were imaged using the technique of Planar Laser Induced Fluorescence (PLIF) and in some cases, compared to simultaneous pulsed-laser schlieren imaging. For the first time, images are obtained which clearly show the nature of the disturbances in an intermediate chemical species (OH) created by the variations in the strength of the leading shock front associated with the transverse wave instablity of a propagating detonation. The images are compared to two-dimensional, unsteady simulations with a reduced but realistic model of the chemical reaction processes in the hydrogen-oxygen-argon system. We interpret the experimental and numerical images using simple models of the detonation front structure based on the "weak version of the flow near the triple point. Both the unsteady simulations and the triple point considerations are consistent with the creation of keystone shaped regions of low reactivity behind the incident shock near the end of the oscillation cycle within the "cell" created by two counterpropagating transverse waves.

Abstract #156

On the Location of the Chapman-Jouguet Surface in Gaseous Detonations Close to the Limit of Propagation

Michael Weber, Herbert Olivier, Hans Grönig, Jörg Biegling

The location of the sonic surface x_s in a cellular detonation is measured by the use of time-resolved schlieren photography for stoichiometric oxy-hydrogen mixture (diluted with 40 % argon and pure) and for stoichiometric oxy-acetylen. This is done by fixing a thin blade in the middle of a detonation tube, whose edge faces the incoming detonation front. A weak shock wave forms at the edge of the blade as soon as it is engulfed by the front. This weak shock separates from the edge when the absolute gas velocity has decreased from its highly supersonic value (directly behind the front) to the speed of sound. After separation the absolute velocity of the shock is low and becomes nearly constant. This is explained as an indication of the proximity of the sonic surface and the CJ-surface. Furthermore

it is shown, that the ratio of x_s and the cell size l rises with pressure, and the influence of the proximity of l to the tube diameter is small. In addition a diagonal-mode detonation was observed with l equal to the diagonal D of the utilised tube with square cross-section. This mode was defined by Hanana et al. (1999).

Abstract #178

Temperature Profiles and their Influence on the ZND Detonation Structure

Luc Bauwens, D. Scott Stewart

High activation energies usually lead to a detonation structure made up of a shock followed by a subsonic deflagration structure that includes a long induction zone in which temperature changes are of the order of the inverse activation energy, and finally a narrow zone of intense reaction. But it has been known at least since Kassoy and Clarke (JFM, 1985) that, in a subsonic stream of reactive mixture delivered at a fixed origin, this deflagration structure cannot exist, if the Mach number is above the inverse of the square root of the ratio of the specific heats at the origin. On the other hand, it is clear that ZND solutions exist for arbitrary heat release models and arbitrary Mach numbers above the Chapman-Jouguet value, and that similar underdriven steady solutions also exist under the same conditions up the the sonic point (which appears then at incomplete reaction). This apparent contradiction is addressed in detail; it is found that a number of structures are theoretically possible, including, in addition to the zone of intense reaction, which is thin at high activation energies, either an induction zone, or a completion zone, or both.

Condensed Phase Explosions/Detonations

Abstract #221

Calculation of the Effect of a Tank Partitioning on a Kerosene Explosion

J.M. Pascaud, P. Gillard, I. Sochet, J. Brossard, A. Moreno,L. Delrieu

The aim of this work is to present a simple modelling in order to predict the evolution of the thermodynamical characteristics of the combustion of kerosene droplets in each compartment of a closed or a vented vessel. The basic characteristics of the model have been developed for the ignition and the combustion of propulsive powders and adapted to liquid fuels with appropriate parameters linked to simplified kinetics. A simple representation of the combustion phenomena based on energy transfers and the action of specific molecular species is presented. The fuel ratio of the mixture is defined by the experimental determination of the partial pressure of the kerosene vapors. The total mass rate of gaseous substances due to the difference of pressure between adjacent compartments or the surrounding atmosphere is calculated by the standard orifice equations. A calculation methodology is developed to simulate the transmission of the explosion from one

compartment to another adjacent compartment by the means of the hot flow through the shared orifice and finally to generalise this methodology to a complex multi-partitioned structure. The model allows to study in each compartment the influence of various parameters such as the fuel ratio of the mixture, the size of the inner openings or the vent areas and the effect of simple additional structures. The theoretical results have been compared with data obtained in the course of experiments performed in a small vessel volume (Vo= 13.2 l) and indicate correct preliminary tendencies.

Abstract #185

Detonation Properties of a Model Condensed-Phase Explosive with a Pressure Sensitive Rate Law

Tariq D. Aslam

During the course of modeling detonations in condensed-phase explosives, one typically resorts to empirical models for describing both the rate of chemical energy release and the equation of state of the explosive. The model examined here incorporates a pressure sensitive rate law, and an ideal equation of state, with \gamma=3, appropriate for a condensed-phase explosive. This particular model has been studied theoretically using a weakly-curved, quasi-steady asymptotic approach called detonation shock dynamics (DSD). The asymptotic theory yields an intrinsic propagation law for the detonation shock front. In particular, there will be a relation between the normal detonation shock speed, the acceleration of the normal detonation speed, the second derivative (along the shock) of the detonation speed and the curvature of the shock. One of the primary focuses of this paper will be to carry out direct numerical simulations (DNS) of the model and investigate the diameter effect in unconfined charges of explosives (planar geometry) for various charge diameters and pressure sensitivity parameters. To treat the resulting multi-material flow, an adaptive mesh refinement strategy is used in conjunction with the ghost fluid algorithm. Phenomenologically, we find that the low sensitive rate laws can support a steady traveling wave for arbitrary stick radii, while for more sensitive rate laws we find that there is a critical radius, below which a steady traveling solution doesn't exist. We find that the DSD theory is qualitatively accurate, and quantitatively accurate when the detonation is stable and not near failure.

Abstract #64

On the Potential of RDX Dust Detonations for Minefield Breaching

S.B. Murray, F. Zhang, I.O. Moen, P.A. Thibault, M.A. Baker

Fuel-air explosives (FAE) are used in a variety of military applications. While FAE has certain advantages, the detonation pressures are generally low (e.g., 2 MPa) when conventional hydrocarbon fuels are employed. The present study assesses the potential of high-explosive RDX dust for generating higher

pressures. A thin-walled detonation tube was used to create dust suspensions in the first part of the study. Dispersal was facilitated by high-pressure air. Explosive charges were used for initiation purposes. The detonation velocities recorded by a streak camera and the detonation pressures measured by piezo-electric transducers were found to be in general agreement with the Chapman-Jouguet theory. Considerable variability in the pressure data suggested that the dust concentration in the immediate vicinity of the transducer was dominating the measurement. The critical charge mass for direct initiation was found to decrease monotonically with increasing dust concentration. The second part of the study focussed on the possible advantages of inducing deflagration-to-detonation transition (DDT) in a fuel-air cloud incorporating a 100-mm thick RDX suspension near the ground. A steel detonation tube of 80-mm diameter filled with lean acetylene-air was employed for this purpose. Various ignition schemes were used to tune the transition distance. Pressure measurements near the end wall showed that RDX is more effective than aluminum at enhancing the hybrid detonation with peak pressures increasing monotonically with dust concentration. An upper limit in concentration was not realized because of the molecular explosive nature of the dust. Peak pressures during DDT were more than twice the usual detonation pressures.

Dust and Metal Containing Flames

Abstract #147

On Optical Diagnostics for Oxide Particles and Temperature Measurement in Metal Containing Flame

Igor S. Altman

The work is devoted to the discussion of the principle possibility of metal containing flame diagnostics by its thermal radiation. It is shown that the temperature usually obtained by the multi-color method may be incorrect temperature of oxide particles generated within flame. It is due to the exponential spectral dependence of the emissivity of the emitting oxide particles. It is shown that in the case of real temperature experimentally obtained, the properties of emitting oxide particles differ significantly from bulk material. The substance of these oxide particles contains a large number of defects. This may lead to necessity to take into account the energy of defect formation when calculation of heat evolution at metal combustion.

Abstract #113

Burning Velocity Measurements in Aluminum-Air Suspensions Using Stabilized Dust Flames

Samuel Goroshin, Massimiliano Kolbe, John Lee

Laminar burning velocity is an important combustion characteristic of the premixed combustible mixture. The majority of experimental data on burning velocities in gaseous mixtures was obtained with the help of the Bunsen conical flame. Hans Cassel was the first to demonstrate that suspensions

of micron-size solid fuel particles in a gaseous oxidizer can also form self-sustained Bunsen flames. Dust flames in comparison to gas flames are thicker, may be influenced by radiation heat transfer in the flame front, respond differently to heat losses, and are fundamentally influenced by the particular flow configuration due to the particles inertia. With greater sensitivity to a specific experimental situation the introduction of the very concept of the fundamental flame speed may be problematic for dust combustion. The present work investigates to what degree burning velocities derived from Bunsen cone depend on experimental conditions (i.e. flow rate and nozzle diameter). Modified experimental apparatus permits stabilization of the aluminum Bunsen-type dust flames on conical nozzles with accurate measurement of the dust concentration and dust flow rate. Experimental results show that burning velocities in aluminum-air suspensions considerably increase with the increase of flow rate and decrease with increase in nozzle diameter. Theoretical estimations show that radiation heat transfer and flame curvature effects are small and can not alone explain the observed experimental trends. Thus other effects such as heat losses and (or) peculiarities of the two-phase flow dynamics might be responsible for the dependence of burning velocity on the flame scales observed in the present work.

Abstract #210

Interesting Flame Propagation Pattern of Gas Flame Interacting With Dust Deposit

Shou-Xiang Lu, Li Zhang, Zi-Ru Guo

The acceleration of gas flame propagating over dust deposited on the bottom of a flame acceleration tube is studied experimentally. When premixed gas is ignited in one end of the tube and flame accelerates forward, transient flame of three front structure is induced. After a short time, the three front flame becomes a complex gas-dust flame. The transient three front flame structure consists of a gas flame, a forward dust flame and a backward dust flame. The reason of the backward dust flame occurrence is that a delay or induction time is necessary for deposited dusts lifted and ignited. Because of the existence of the backward dust flame, the curve of flame velocity along the tube tangentially gives a birdlike configuration.

Cellular Structure III

Abstract #154

The Influence of Detonation Cell Size and Regularity on the Propagation of Gaseous Detonations in Granular Materials

Torbjorn Slungaard, Tom Engebretsen, Otto K. Sonju

Filters consisting of granular materials can be used to transform a detonation wave into a fast deflagration wave or to totally extinguish the flame of a detonation wave. Whether a detonation wave fails or not by a given filter type can depend

both on detonation cell size and regularity. A research project for finding the limits for transmission of a detonation wave through a granular filter is completed. Both spherical glass beads and crushed rock were tested. Varying the initial pressure of the detonating gas mixture in the range 0.02 - 1 bara, controlled the cell size. Adding of argon was used to vary the detonation cell regularity. Eight piezoelectric pressure transducers recorded the pressure-time profile of the detonation wave. These pressure signals were used to calculate the detonation wave speed upstream, inside and downstream of the granular filter. To detect whether the flame of the detonation wave was extinguished or not, an ionisation probe was used in some experiments. The results are used to establish the conditions for total flame extinction in a granular filter. In addition it is found an approximate range for direct transmission of a detonation wave with irregular cell structure. For argon dilution resulting in regular detonation cells this range is changed. In the direct transmission range, the detonation wave regains full velocity immediately downstream of the granular filter. The range producing a fast deflagration downstream of the granular filter with the possibility of deflagration to detonation transition (DDT) is also found.

Abstract #136

Multi-Headed Detonations in Oxygen-Aluminum Mixtures: Two-Dimensional Numerical Simulations Using Adaptive Grid Refinement

Krzysztof Benkiewicz, A. Koichi Hayashi

In the present paper the two-dimensional computer simulations of the detonation in the oxygen-aluminum particles mixture are presented. The continuous approach has been adopted. The gas phase is treated as the multi-component mixture that obeys thermally perfect equation of state. The solid phase burning is modeled using a simple formula that describes the solid/liquid aluminum consumption rate, while depending on the gas temperature the combustion products is either aluminum oxide (Al2O3) or aluminum monoxide (AlO). It is also assumed that at high temperatures (T>3500 [K]) aluminum oxide (Al2O3) starts to decompose into aluminum monoxide (AlO) and oxygen (O2). The computations have been performed using the Adaptive Mesh Refinement combined with the high-order, contemporary numerical methods. The AMR technique utilizes the set of hierarchical grid layers (patches) with increasing spatial resolution in order to improve the resolution near shocks, contact discontinuities or high gradients. This set of grid patches is self-adopting to the flow conditions. This technique leads to precise solution of the detonation front. The computations show the development of the triple points, incident shocks, Mach stems and local explosion centers. Finally the transition into the multi-headed detonation is observed. The structure of the detonation front and the flow field behind it are highly transient and complicated, and it is difficult to predict if this mode of propagation is stable or not. It is

probably the first time when the detailed structure of the detonation front in the oxygen-aluminum mixture has been obtained in numerical simulations.

Abstract #163

Numerical Simulation of Detonation Cells in Hydrogen-Air Mixture with Suspended Aluminum Particles

Boris Khasainov, Bernard Veyssiere, Wilfrid Ingignoli

We present preliminary results of 2D numerical gasdynamic study of detonation cell structure in hybrid two-phase hydrogen-air mixture with suspended aluminum particles of different sizes. The results are in qualitative agreement with observed effects of particles on detonation cell structure and improve existing knowledge of detonations in hybrid mixtures with aluminum particles. Better quantitative agreement with the experimental data is attempted by improving description of kinetics of gaseous reactions and effect of particles on the heat release rate.

Detonation Limit/Failure

Abstract #153

Detonation Propagation in Hydrogen-Oxygen Mixtures with Concentration Gradients

Kazuhiro Ishii, Yuichi Takahashi, Takao Tsuboi

A study is made on detonation waves propagating in mixtures with concentration gradients in the direction normal to the propagation direction. By sliding a plate attached to a detonation tube, a dilution gas is diffused into the detonation tube in which a stoichiometric hydrogen-oxygen mixture was initially charged. Changing the opening duration of the plate causes mixtures with various concentration gradients. The experimental results show that detonation initiation is governed by properties of the most detonable part of the mixture. From observation of smoked foil records, the boundary between a cellular and a diamond-shaped pattern, which is formed by triple points originating from cellular structure, indicates a propagation limit owing to the concentration gradient.

Abstract #121

The Failure Mechanism of Detonations Propagating in Porous Wall Tubes

Matei I Radulescu, Marianne Huot, John H.S. Lee

The gas ignition mechanism in real detonation waves is believed to be a combination of the classical ZND mechanism of ignition by leading shock compression supplemented by the intense mixing generated by transverse wave interactions. To clarify the duality between these two simultaneous mechanisms, damping experiments are carried out in tubes lined with a rigid porous material (steel mesh). On short propagation length scales (one tube diameter) the porous wall acts like an acoustic absorber only and selectively dampens the transverse wave system in propagating detonations. Global mass divergence to the permeable porous wall, which weakens the leading shock,

acts on length scales larger by an order of magnitude. Experiments are performed with acetylene-oxygen mixtures with various amounts of argon dilution. The detailed study of the attenuation process of these detonations revealed two fundamentally different failure mechanisms. Stable detonations (high argon dilution), which approach the idealized ZND structure, fail by the mass divergence mechanism alone, on a length scale of approximately 10 tube diameters. The velocity dependence of stable detonations on tube diameter, hence on the amount of mass divergence, is very strong. In contrast, unstable detonations (no argon dilution) are quenched immediately upon entrance in the porous wall section. Flow visualization revealed the rapid attenuation of transverse waves and disintegration of the detonation into a turbulent flame. Under-damped unstable detonations exhibit a very weak velocity dependence on tube diameter, which reflects their strong ability to re-generate new transverse waves. The present results show conclusively the prime role played by transverse waves in the propagation mechanism of typical unstable detonations displaying an irregular cellular structure. Only for artificially stable detonations, the classical mechanism of ignition by shock compression plays the lead role.

Abstract #104

Detonation of Propane-Air Mixture in the Perforated Tube and Release of Detonation Products

V.I. Tarzhanov, V.I. Sdobnov, A.D. Zinchenko, V.A. Ogarkov, V.V. Vlasov

RFNC-VNIITF proposed the way and TSD-01M facility, which are used to investigate basic mechanisms of the deflagration-to-detonation transition "under the magnifying glass". The facility has a small internal partially perforated tube. The purpose of this tube is to create hot detonation products (HDP) of the fuel mixture and their release from it into the main tube of the facility through the holes arranged uniformly in staggered rows over the surface of the small tube portion. Experiments were performed with measuring chambers arranged above holes of the perforation tube portion, just at the front end and at the back end of this portion. Pressure-time ratios in measuring chambers allow calculation of HDP mass injected into the chamber through one hole in a tube wall as well as determination of the jet head velocity in the chamber and sound velocity in HDP jet, i.e. its temperature assessment, by pulse shift and oscillations. Obtained profiles of the detonation wave at different perforation of the tube portion indicate, firstly, absence of detonation quenching and, secondly, a shortened wave profile at the perforated tube portion, if compared with the profile in a smooth tube. One-dimensional computer code "Prognoz" is developed to simulate viscous gas detonation with the outflow of detonation products thorough the holes of the perforated tube.

Gasless and Dust Containing Flames

Abstract #218

The Convective-Conductive Mode of the Reaction Zone Propagation: A New Mechanism of Combustion of 'Gasless' Systems

Boris S.Seplyarskii

A convective- conductive mechanism of combustion has been proposed for explanation of an anomalously high combustion velocity observed in the 'gasless' systems titanium - carbon black and titanium - carbon black - polystyrene at one-dimensional infiltration of the impurity gases. Analysis of the experimental and theoretical data shows that under the condition of the impurity gas release the convective mechanism of combustion can occur only at spreading of the melt layer of one of the reagents forced by the gradient of the impurity gas pressures. Physical and mathematical models of convective-conductive combustion of 'gasless' systems are proposed for the directed infiltration of the impurity gases. They have been analyzed with the use of the approximate analytical and numerical methods. It has been found that at the initial stage of combustion the growth of the front velocity and the gas pressure obeys the exponential law provided there is a free volume exceeding that of the sample. The necessary and sufficient conditions of occurrence of the convective regime of the 'gasless' system combustion have been formulated. Analysis of the proposed model provides explanation to the experimentally observed difference in the specific feature of the 'gasless' system combustion at counter-front, co-front, and bilateral infiltration of the impurity gases.

Abstract #217

Adiabatic Waves of Gasless Combustion: 3D Simulation

T.P. Ivleva, A.G. Merzhanov

We consider a three-dimensional system of reaction-diffusion equations describing the propagation of spinning combustion waves along a thermally insulated cylindrical sample of solid fuel. We consider the heat release and heat transfer only. The given mathematical model of the process was studied numerically by using the method of finite differences. The applied spatial grid was non-uniform with an unfixed number of nods, and it was adapted to a solution. The mechanism of hot spots moving was described and analyzed for many found modes. The data presented in this paper are associated with established modes only. There are two kinds of modes: the modes with invariable front structure (at small sample radius) and the non-stationary modes with multiple transformations of the front during a period. In the latter case, blinking of hot spots is observed on the sample surface. Flickering of hot spots can be both synchronous and by-turn. The hot spots can move both in a right-side and left-side way. It was found that for the spinning combustion the average velocity of the front propagation was approximately identical to the theoretical

velocity of stationary combustion wave propagating through condensed phase under adiabatic conditions. The mean front velocity slightly decreases with increase in the sample radius. Also the non-uniqueness of combustion modes was found. The areas of existence for these modes have been determined.

Abstract #43

Propagation and Extinction of Unsteady Spherical Spray Flame Fronts

J.B. Greenberg

The question of the ignition of a mist of fuel droplets is of prime importance in a variety of aeronautical contexts. There is sparse experimental evidence available in the literature and theoretical efforts have generally resulted in rule of thumb formulae. In the current work the related problem of a spherical flame front propagating through a fuel rich mixture of fuel droplets and air is examined theoretically for the first time. The SVF (slowly varying flame) framework is adopted for the analysis. Upon attaining their boiling temperature the droplets are assumed to vaporize in a vaporization front, downstream of the propagating flame front, whose location as a function of time is determined as part of the solution. An evolution equation for the flame front is derived. It is shown that the droplets supply a heat loss term in this equation involving the droplet loading and the latent heat of vaporization of the liquid fuel. Calculated results demonstrate the way in which increasing the droplet loading beyond some critical value actually causes the flame front to extinguish.

DDT

Abstract #27

Effects of Boundary Layers on Shock-flame Interaction and DDT

Alexei M. Khokhlov, Vadim N. Gamezo, Elaine S. Oran

The effects of boundary layers on shock-flame interactions and deflagration-to-detonation transition (DDT) are investigated using two- and three-dimensional, time-dependent, reactive Navier-Stokes fluid-dynamics simulations of shock-tube experiments. Simulations show a complex sequence of events, starting from the interactions of an incident shock with a laminar flame and the formation of a flame brush. The bifurcation of the reflected shock, due to boundary layer effects, creates a rapidly growing, leading oblique shock followed by a recirculation region. Flame becomes entrained in the recirculation region and attached to the bifurcated shock. Three-dimensional simulations show that the highly-deformed flame surface is spread out through the entire region between the reflected shock and the end-wall. The schlieren pictures made from three-dimensional data show a reflected shock followed by an approximately constant-volume region of burning. The burning region moves with the velocity of the reflected shock and is characterized by the pressure that is less than the pressure of a Chapmen-Jouguet detonation. A reactive bifurcated structure increases the energy-release rate in the system, leads to the formation of Mach stems in the middle of the shocktube, and generates multiple hot spots behind the Mach stem, thus facilitating DDT. The DDT process finally leads to the emergence of a self-sustained cellular detonation.

Abstract #135

DDT in Methane-Air Mixtures

M. Kuznetsov, G. Ciccarelli, S. Dorofeev, V. Alekseev, Yu. Yankin, T.H. Kim

Considering the common use of methane gas in the chemical process industry there is a lack of detonation phenomena data in the literature for methane-air mixtures. This is due to the relatively low detonation sensitivity of methane-air, and thus the need for large-scale apparatus. Experimental results from a study on the critical condition for DDT in methane-air mixtures are presented in this paper. Tests were performed in two different detonation tubes, one with an inner-diameter of 174-mm and the other 520-mm inner-diameter. With a blockage ratio (BR) of 0.3, propagation in the quasi-detonation regime was observed for mixtures with 8, 9.5, 10.5, and 12 % CH4 in the 520-mm tube and 9.5 and 11% CH4 in the 174-mm tube. In tests with a BR= 0.6, propagation DDT was not achieved in either tube for any methane-air mixture. The results indicate that for a blockage ratio of 0.3 the critical condition for DDT can be characterized by the d/lambda = 1 criterion proposed by Peraldi et al. However, for BR = 0.6 it was found that the critical value was significantly higher. The data also

shows that the critical condition for DDT can be better described by L/lambda = 7, where L is a characteristic size for of the channel volume between orifice plates which depends on the orifice plate dimensions and spacing. This is in good agreement with previous data obtained for other hydrocarbon and hydrogen mixtures with irregular detonation cellular structure.

Abstract #172

The Effect of Nitrates on Deflagration to Detonation Transition

P. Pinard, A.J. Higgins, J.H.S. Lee, S.B. Murray

Renewed interest in pulse detonation engines has focused attention on the problem of deflagration to detonation transition (DDT) in fuel-air mixtures. A prohibitively large deposition of energy is required for direct initiation of higher-hydrocarbon fuels in air. Consequently, a method is sought to reduce the run-up distance for DDT. It has been proposed that the addition of nitrate-based sensitizers typically used in diesel fuels could increase the sensitivity of hydrocarbon fuel-air mixtures by increasing the chemical kinetic rates, resulting in a reduction in run-up distance. Experiments were carried out in order to quantify the effect of NO2 addition to propane-O2-N2 mixtures. The run-up distance was established for a baseline C3H8-O2-N2 mixture at 293 K and 1 atm. NO2 was then added to this mixture as a 1% to 10% fuel additive, and finally O2 was added to the baseline mixture in order to achieve the same stoichiometry. The results show a comparable reduction in run-up distance for both NO2 and O2 experiments, indicating that the effect of NO2 is energetic rather than kinetic. It is also found that the propagation in the turbulent flame regime is comparable for both the baseline and the sensitized mixtures. This confirms that the majority of flame acceleration over the run up distance to detonation is dominated by turbulent mixing. It also suggests that a significant reduction in run-up distance would ideally be achieved through a dual approach involving a mechanism for enhancing the turbulent mixing phase, and chemical sensitization for the final onset of detonation.

Abstract #174

Sensitization of Pentane-Oxygen Mixtures to DDT via Cool Flame Oxidation

Massimiliano P. Romano, M.I. Radulescu, Andrew J. Higgins, John H.S. Lee

Experiments in a heated Pyrex tube have examined the effect of "cool flame" oxidation on the run up distance to detonation in pentane-oxygen mixtures. From fundamental considerations it is known that the introduction of free radicals into a combustible mixture would make it more sensitive to detonation by reducing its induction time. One of the interesting features of hydrocarbon oxidation is the existence of a temperature range that leads to a two-stage ignition

mechanism. The first stage follows a low temperature dissociation reaction that leads to formation of free peroxide radicals and onset of a chemiluminescent phenomenon referred to as "cool flame". The second stage is controlled by the high temperature dissociation of hydroperoxides.

In the present study, an attempt it is made to measure the run up distance for deflagration to detonation transition (DDT) in a pentane-oxygen mixture when it is spark ignited while undergoing cool flame oxidation. Particular attention was given to determine the conditions for the onset of cool flame to be able to predict the instant of appearance of the chemiluminescence. The pentane-oxygen mixture was spark ignited at different moments before and after the onset of cool flame and run up distances to detonation were compared. The results show a decrease in run up distance when the mixture is spark ignited prior to the onset of cool flame.

Ignition Phenomena

Abstract #2

The Droplet Ignition in High Pressure Condition with Natural Convection

Sang Hun Kang, Seung Wook Baek

A simulation of the droplet combustion in the high-pressure environment is very important in understanding the fundamental phenomena of liquid rocket, gas turbine and diesel engine combustion. Therefore, a more reliable ignition model of a droplet under high pressure condition is highly desirable. In this paper, the ignition model of the n-heptane droplet is suggested for high pressure environment and solved for the ignition delay. Its variations with the change in the ambient pressure and temperature are discussed for the cases with/without gravity so that the natural convection effects on the droplet ignition delay time are also examined. The natural convection effects are considered by introducing so-called the time scale correction method. The results show that the logarithmic ignition delay time linearly decreases with the inverse of the ambient temperature, and its decreasing slope is independent of the ambient pressure. Thereby, the overall activation energy is found not to be affected by the pressure variation. As the pressure increases, the ignition delay time gets shorter since the droplet vaporization rate is enhanced. But, at a higher ambient pressure, the reduction rate in the ignition delay time becomes smaller. The natural convection effect is also found to make the ignition delay time shorter due to the improved heat feedback to the droplet.

Abstract #165

Thermal Explosion in a Droplet-Gas Cloud with Chemical Reaction of General Order

V. Bykov, I. Goldfarb, V. Gol'dshtein, J.B. Greenberg

Theoretical study of the input of oxidizer presence to the phenomenon of thermal explosion in combustible gaseous mixture with evaporating fuel droplets is presented. The

suggested physical model is described by four highly non-linear ODEs. The analysis of the mathematical model is performed analytically on the basis of the method of integral manifolds (MIM). The accepted mathematical approach permits to the study of thermal explosion in both fuel rich and fuel lean mixtures. Possible types of dynamical behavior of the system are studied and parametric regions of their existence are determined analytically. It is pointed out that the present model generalizes previous results for fuel lean combustible mixtures, which are a particular case of the current model. Two main types of regimes (conventional explosive and delayed) were uncovered in the fuel rich case. Peculiarities of these dynamical regimes are investigated and their dependence on physical system parameters analyzed. In particular, explicit formulae for the total ignition and delay times are developed and found to agree with the predictions of direct numerical simulations.

Abstract #92

Modeling the Ignition of Sprays

Chrys Correa, Berthold Schramm, Juergen Warnatz

The ignition of sprays is important for many industrial processes, such as the autoignition in diesel engines. The characteristic ignition delay time due to radical chain reactions can be described using detailed reaction mechanisms. The use of such detailed mechanisms in the simulation of 3-D instationary processes is too computationally expensive due to the large number of species, radicals and reactions involved. In this paper, a simplified ignition model will be presented which is based on a detailed reaction mechanism. Itis assumed that the complete radical pool formation can be represented by a single species acting as a progress variable, and therefore a conservation equation needs to be solved only for that species. This species should have a very low concentration during the ignition delay time and show a sharp increase in concentration during ignition. The concentration of this species should show a monotonic behavior. In this work, CO was chosen as the representative species. In order to compute the reaction rate of CO, trajectories in homogeneous reactors were traced for different mixture fractions (z), pressures (p) and temperatures (T), and the reaction rates of CO (rCO) was tabulated as a function of z, p, T and the CO concentration (CCO). In turbulent flows, the reaction rate needs to be integrated over a probability density function (pdf). Here, statistical independence of the variables was assumed and a presumed pdf method was used. This ignition model was implemented in a standard engine code (KIVA III) and used to predict the ignition delay time and the position of ignition.

Abstract #17

Classification of Ignition Processes of Premixed Gases

Tobias Brutscher, Wolfgang Leuckel, Henning Bockhorn

One-dimensional ignition processes of quiescent methane-air-mixtures were investigated in detail with the simulation code

INSFLA. On the basis phenomenological considerations it was possible to divide induced ignition processes in three regimes. At large radii of the external energy source the ignition process is dominated by the formation of a pool of radicals (induction time). In this regime a self-sustained flame front has been established when ignition takes place. At small radii and short times of the external energy source it is necessary to reach a critical flame ball size. At the transition between both regimes diffusion of heat and mass during the heat release of the external energy source plays an important role for the ignition process. It was possible to derive simple equations to calculate minimum ignition energies for the different regimes.

Premixed Turbulent Flames III

Abstract #215

The Stability of High Speed Turbulent Deflagrations in Fuel-Air Mixtures in an Obstacle Field

Jenny Chao, John H.S. Lee

In previous studies on the propagation of high speed turbulent deflagrations in obstacle fields in circular tubes, terminal flame speeds are averaged over a few tube diameters. Local velocities taken over a tube diameter are not as meaningful and fluctuate greatly since flames can jet through successive orifices at once. In the present experiment, a 30 cm x 30 cm square cross section tube with a staggered obstacle array of cylindrical rods is used to investigate the fluctuations in the local velocities of high speed turbulent deflagrations, thereby gaining more insight into the propagation mechanisms. For quasi-detonations, it is found that the fluctuations are a result of auto-explosions of quenched pockets of unreacted mixture which are formed from the failure of diffracted detonations. In less sensitive mixtures with large characteristic cell sizes, turbulence and transverse waves that are generated by the obstacles promote auto-ignition in the reaction zone.

Abstract #190

Turbulent Combustion of Spherical Fuel-Rich Hydrogen Pockets

J.B. Bell, M.S. Day, J.F. Grcar, A.E. Lutz

Recent experimental investigations of combustion in diesel engines showed that the initial premix burn creates pockets of soot and fuel that must burn out in a diffusion-flame mode in order to complete the combustion. Understanding the final stages of this process is critical to predicting the emissions of soot and NOx. This effort uses numerical simulations to investigate burnout of diffusion flames that result from the autoignition of rich premixtures created by the injection process. An initial model is developed using hydrogen gas as a combustion fuel. A three-dimensional diffusion flame is established around an initially spherical fuel pocket that is formed when a rich (equivalence ratio of 4) mixture of hydrogen and air ignites. After the premixed ignition, the remaining fuel mixes with the surrounding air by molecular

diffusion and turbulent mixing, forming a wrinkled diffusion flame. The numerical method uses a dynamically adaptive mesh to resolve the flame and turbulent flow field. A detailed reaction mechanism for the hydrogen chemical kinetics and heat release (9 species, 27 reactions) is employed based on the relevant components of the GRI-1.2 mechanism for methane combustion.

Abstract #140

Observation of Flame Structure in Low Damköhler Number Fields

Manabu Fuchihata, Tamio Ida, Yukio Mizutani, Masashi Katsuki

We discussed the flame structure in low Damköhler number fields. Low Damköhler number flames were successfully formed, by a neighboring hot burnt gas stream, in a relatively weak turbulence field of a very lean premixture, which gave a sufficiently long chemical characteristic time. Laser tomography, chemiluminescence detectors, LDV and thermocouple were used simultaneously for observing the lean turbulent premixed flames with silica powder seeded. As a result, the transition of flame structure from a distributed reaction zone to a wrinkled laminar flame was observed in detail by traversing the observation point from upstream to downstream. Further, the flame structures, in which a distributed reaction structure coexists with a propagating flame structure, were observed in the transition region. It was concluded that the propagating flame emerged amid the distributed weak reaction region, and the distributed reaction region was divided up by the propagating flame at the moment. When the propagating flame sufficiently grew, it started to propagate into the lean mixture stream and there is seen no pseudo-distributed reaction zone outside the propagating flame, because it is separated from the lean reactant flow by the flame.

Abstract #50

Investigation of Flamelets in a Turbulent Premixed Flame with a 4-Element Electrostatic Probe and a 2-D LDV

Junichi Furukawa, Toshisuke Hirano, Forman A. Williams

To investigate the statistics of flamelet in a turbulent premixed flame and to obtain components of their burning velocities in a vertical plane above a pipe-flow burner, the local motion of flamelets with respect to gas are measured by specially arranged diagnostics, composed of an electrostatic probe with four identical sensors and a two-color four-beam LDV system. With this technique, the three-dimensional local flame-front-velocity vector is measured by the electrostatic probe for the first time, and simultaneously the axial and radial components of the local gas-velocity vector in a vertical plane above the vertically oriented burner are measured by the LDV system. Two components of burning velocities of planar flamelets can be obtained from these results and are found to be distributed over

different directions and to range in magnitude from nearly zero to a few times the planar, unstrained adiabatic laminar burning velocity measured in the unburnt gas. It may be concluded from these results that turbulence exerts measurable influences on flamelets and causes at least some of them to exhibit increased burning velocity.

Plenary Lecture II

Abstract #P2

Advanced Laser Diagnostics for Reactive Flows

R.K. Hanson

Laser-based diagnostics provide powerful and unique capabilities for non-intrusive measurements in reactive flows. This paper will overview recent progress in the evolution and application of two of the most important diagnostic concepts: tunable diode laser (TDL) absorption, which is a line-of-sight technique with continuous recording potential; and planar laser-induced fluorescence (PLIF) imaging, which yields instantaneous measurements at a large number of points in a plane illuminated by a pulsed laser. Techniques based on these measurement concepts can monitor multiple parameters including species concentrations, temperature, pressure and velocity. Example results will be shown for TDL measurements in a pulse detonation engine and for PLIF imaging in an expansion tube study of supersonic combustion.

Shock Ignition

Abstract #131

Effects of Boundary Layers on Ignition Behind Reflected Shocks

Vadim N. Gamezo, Alexei M. Khokhlov, Elaine S. Oran

Two-dimensional Navier-Stokes numerical simulations were used to study ignition phenomena behind reflected shocks in a stoichiometric ethylene-air mixture. The simulations were performed for a series of Mach numbers of the incident shock, Ms, and two channel widths. The results show that the flow nonuniformities resulting from the interaction of the reflected shock with boundary layers created by the incident shock may strongly affect the ignition process. The reflected shock develops a bifurcated structure consisting of an oblique leading shock, secondary shocks, and a number of vortices. This structure grows substantially before the ignition occurs. For relatively weak incident shocks, or in narrow channels, the leading oblique shock reaches the center of the tube and creates several secondary shocks. Interactions of these shocks with each other and with vortices intensify mixing and create hot spots far from the reflecting wall. Some of these hot spots ignite and produce flames that interact with vortices and generate additional weak shocks and compression waves. This leads to new hot spots and flames, and eventually creates conditions that allow a transition to detonation. Ignitions occur closer to the end wall for stronger incident shocks and larger channels where the influence of bifurcated structures is less pronounced. For the same Ms, weak

ignition producing a flame in a narrow channel occurs sooner than strong ignition at the end wall in a wider channel.

Abstract #225

Ethylene Combustion Studied Over a Wide Temperature Range in High Temperature Shock Waves

P. Cadman, R. J. Bambrey, G.O. Thomas , S.K. Box

The initiation of ethylene combustion (at 0 = 1 and 1.5) was studied over a wide range of temperatures (800-2273K) in shock waves. Ignition delay data showed the presence of 2 or 3 different chemically controlling regimes in the combustion. Figure 1 shows the temperature dependence of the ignition delays of ethylene in N2/O2 mixtures. These were done on two different shock tubes under different conditions with a large amount of fuel (75 and 50% N2 , O2 and fuel making up the _ = 1 and 1.5). At low temperatures (T~900-1000K) the time development of a combustion bubble was tracked via Schlieren techniques and was seen to grow slowly. It was formed away from the backwall of the shock tube at the lower temperatures, a result which was unexpected. Unburnt gas, between the bubble and endwall which was compressed and heated by the latter, exploded and gave rise to a strong combustion wave which travelled back through the partially burning gas. Emission measurements showed the presence of CH*, OH*, C2* and a continuum emission attributed to CO2 * flame bands. C2* was found to be only important in richer mixtures. CH* was formed only ~μsecs ahead of the other diatomics. The spectra of CH* C2* and OH * was tracked from the initial developing combustion bubble. Further work and results on this system will be presented.

Abstract #6

Numerical Studies of Shock Reflection and Ignition

Boliang Wang, Werner Rehm

A new computational-fluid-dynamics code has been developed for the simulation of hydrogen combustion events concerning hydrogen safety analysis. This code describes the feedback of the flow fields with chemical reactions. It considers detailed chemical kinetics for two-dimensional flow fields. Also it is possible to use a two-step kinetic model for global reaction processes. First validation of calculations were performed for ignition induced by shock reflections from an axis of symmetry and from a flat wall with a long narrow gap. The results show a remarkable agreement. With the two-step model, the experimentally observed physical-chemical phenomena can be reproduced. It is also found that the calculated results are strongly dependent on the kinetic scheme applied. Therefore, several schemes from the literature have been studied.

Chemistry in Flames I

Abstract #124

Reactive Flow Calculations with Intrinsic Low Dimensional Manifold Corrections for Convection and Diffusion

Sandeep Singh, Samuel Paolucci, Joseph M. Powers

A method is described which rationally corrects the method of intrinsic low dimensional manifolds (ILDM) to account for the effects of small convection and diffusion. The ILDM method is well suited for spatially homogeneous problems and provides a systematic way to overcome the severe stiffness which is associated with full models of detailed kinetics and thus significantly improves computational efficiency. Significant errors can arise however when the ILDM method is applied to systems which have convection and diffusion. Motivated by techniques from center manifold theory, and using the ILDM as a reference manifold, we project our entire system of equations onto a new basis, which is segregated into fast and slow sets of equations. The fast scale equations are equilibrated, requiring the solution of an elliptic equation in space. The slow equations are allowed to temporally evolve. Improvements in predictions relative to those of the traditional IDLM method are shown for a simple model problem.

Abstract #87

Effect of Nitrogen-Oxide Addition on Low-Temperature Powling-Burner Flames

Masahiro Furutani, Yasuhiko Ohta, Yasushi Niimi, Masakazu Nose, Shizumo Fujikawa

The burned gases is always introduced into / mixed with fresh mixtures in the reciprocating-piston internal combustion engine with / without exhaust-gas recirculation. The effect of burned gases contained in the mixtures is not weak on the preflame reactions prior to the hot-flame ignition. Temperature dependence became a quarter on the ignition induction time. It would be indicated that some nitrogen-related compound are closely take part in the ignition promotion/retardation phenomena. Flat low-temperature flames were established on a Powling burner using rich diethyl-ether/air mixtures. Nitrogen monoxide or nitrogen dioxide was added into the mixtures, and the temperature development, chemical-species history and emission spectra from the low-temperature flames were examined to elucidate the effects of nitrogen oxides on low-temperature oxidation of fuel/air mixtures in the most simple, undoubted system, and to find out ignition control procedures to realize premixed compression-ignition (HCCI) engines. Nitrogen-oxide addition retarded the cool-flame appearance and reduced the distance/time between cool and blue flames where the excited oxygen molecule could be found. Nitrogen oxides promote fuel decomposition reactions in the post cool-flame period which results in rapid blue-flame onsets, but the pre cool-flame reactions are emaciated. The knowledge would

contain a key factor to find real ignition-control procedures for the novel internal combustion engine systems.

Abstract #146

Microscopic Shadowgraph and CH-Band Emission Images of Micro-Jet Diffusion Flames

Tamio Ida, Manabu Fuchihata, Yukio Mizutani

To elucidate the nature of the mixing process in the structure of turbulent diffusion flames, it is extremely important to understand the change of the time-dependent stepwise components of the macroscopic and microscopic spatial structure of the flame. The experimental object was to store fundamental data of flame characteristics and to extract problem points by micro flame. An attention was given to initial conditions of the burner port, which are the hydrodynamic factors which make up the Reynolds number, and as a function of the Reynolds number, the range in which steady-state diffusion flames can be formed were observed. This study was visualized at CH image by direct photography and OH image by laser shadowgraphs. Especially, it was found that the buoyancy length from the end of the burner and the flame area thickness, which depend on the molecular diffusion rate of the fuel, were constant regardless of the initial burner port conditions.

Flames

Abstract #98

Modelling of Premixed Counterflow Flames Using the Flamelet-Generated Manifold Method

J.A. van Oijen, L.P.H. de Goey

The recently introduced reduction technique called flamelet-generated manifold (FGM) method is used to compute premixed methane/air counterflow flames. In the FGM method the ideas of the manifold and the flamelet approach are combined: a manifold is constructed using one-dimensional flamelets. In this paper the effect of flame stretch on the accuracy of the FGM method is investigated. In the case of unit Lewis numbers a one-dimensional manifold is able to model the main effects of flame stretch. A manifold with two progress variables reproduces the results computed using detailed kinetics almost exactly. When non-unit Lewis numbers are used, the enthalpy and element composition of the burnt mixture change, which influences the mass burning rate significantly. If these composition changes are included in the manifold using an additional controlling variable, the results agree well with detailed computations.

Abstract #94

Auto-Turbulizating Regimes of Gaseous Spherical Flames

Ya.A. Gostintsev, A.G. Istratov, N.I. Kidin, V.E. Fortov

A spherically propagating flame is a unique object for experimental and theoretical study of the phenomena of spontaneous instability and auto- turbulization of flames formulated more than half a century ago and being actual up to

now in accordance with at least two application problems: combustion in turbulent-flow and deflagration to detonation transition. It was experimentally established that hydrodynamical instability of propagating spherical flames results in the limiting self-similar turbulization mode with the time dependence of radius being 3/2.

At the conditions of experiments essential effects have the floating of burning sphere in gravity field when the instability dependence decelerates and burning sphere transforms to thermic. The comparison of characteristic times of burning at the different regimes and floating times allows establishing the area where such influence is not essential in coordinates - flame radius- normal burning velocity; in this case the spontaneous turbulization process is realized completely and there is combustion with the same power time dependence of radius being the degree 3/2.

The theoretical treatment allows constructing the most possible scenario of auto-turbulization of free spherical flames with the following space-time stages: development of hydrodynamical instability laminar-flames leading to the curving and fractalization of flame surface, its self- acceleration and turbulization of combustion zone formation of large scale vortex structures due to Taylor instability of the discontinuity surface between cold fresh mixture and hot products in the gravity field.

The role of combustion heas two circumstances. At first, combustion causes and supports accelerating propagation surface that becomes the fractal with the degree 7/3. The same fractal degree has the flame in turbulent flow with rather large turbulence intensity. Secondly, turbulent energy dissipation at the limiting case of propagation appeared to be the constant value and to be determined via combustion parameters - normal burning velocity in the forth power devided by viscosity. Estimations show that dissipation has the value of several percents of the kinetic energy growth in gaseous flow due to expansion of burning sphere.

Abstract #34

Steep Pressure Interactions With a Methane-Air Flame: The Inclusion of Multi-step Chemistry

Xin-She Yang, Andy C. McIntosh, John Brindley

The numerical computation of structures of one-dimensional methane-air flames over a wide range of conditions has been made. Several reduced schemes have been proposed and reproduce most of the chemistry from the earlier work. Most of the work on multi-step chemistry has focused on the computational simulations at steady-state or on using the partial-equilibirum approximations, for modelling the multi-layer structure of methane-air flames. In this paper, we intend to study sharp pressure disturbances and their interactions with premixed flames charactersed by three or four step chemistry. We focus on the effect of a sharp pressure drop on the time response and the effect of sharp pressure drops on methane

premixed flames with multi-step chemistry. The time response of the mass burning rate of premixed flame for different values of minimum pressure has also been calculated so that a critical minimum pressure, leading to extinction of the premixed strained flame, is found, depending on the three activation energies and Lewis numbers. For sudden pressure drops, the flame is extinguished, if the pressure drop is sufficiently large. For large activation energies and low Lewis number, the flame is very susceptible to pressure changes.

Detonation Chemistry

Abstract #63

Correlation between Dynamics and Chemical Kinetics Parameters in Detonation Waves

L. Desweemer, L. Thill, M.H. Lefebvre, P.J. Van Tiggelen

The work focuses on the correlation between experimental properties of gaseous detonation waves, namely the ratio of the length of the cellular structure (L) and the mean wave velocity (D), and the calculated mean induction time (tind). The ratio L/D represents the period of the detonation wave. Previous workers have noticed a linear correlation between the induction time and this ratio. However, the correlation factor seems not to be universal and depends sometimes on the chemical composition of the reactive mixture. Moreover, close to the detonation limits, the simple linear relation does not stand anymore. In this work, we try to elaborate more on the relationship between all these parameters. Experimental evidences and calculations lead to the definition of two types of detonation failure: a dynamics and a chemical kinetics failure. The paper investigates these correlations for detonation waves at various initial conditions, namely: - variable equivalence ratio of the mixture with different initial pressures, - variable inhibitor content with different fuel compositions, and - various initial pressures in three different tube cross-sections, including rectangular and diagonal types of detonation waves.

Abstract #37

Two-Step Chemical-Kinetic Descriptions for Detonation Studies

B. Varatharajan, F.A. Williams

Simplified two-step chemical-kinetic descriptions have been developed for detonation of practical fuels like acetylene, ethylene, and JP-10. For all of these fuels, the two-step mechanism consists of a fuel-consumption step that produces radicals and a CO-oxidation/radical-recombination step that proceeds at the rate the of the elementary H, OH recombination reaction. The calculated ignition times and the temperature histories using this two-step mechanism are in excellent agreement with those from a detailed mechanism consisting of 174-steps among 36 chemical species. These mechanisms are useful for studying detonation structure and stability, and predicting pulse detonation engine performance in multi-dimensional CFD calculations.

Acoustic Phenomena

Abstract #110

Propagation of a Flame from the Closed End of a Smooth Horizontal Tube of Variable Length

Steven Kerampran, Daniel Desbordes, Bernard Veyssiere

Flame propagation has been studied from the closed end to the open end of a tube having a square cross section (40 mm x 40 mm) and a variable length (0.6 m < L < 8.1 m, by steps of 0.5 m). For stoichiometric propane air mixtures, the flame trajectory exhibits an oscillatory behaviour for all tube lengths, while pressure records show oscillations, the frequency of which corresponds to the fundamental mode of vibration of the column of fresh gas contained in the tube. These results corroborates our previous observations made at smaller scale. The major role played by acoustics is displayed and confirmed by experiments performed with mixtures where helium has been substituted to nitrogen. Detailed analysis of the initial stage of flame propagation shows that the flame accelerates as the consequence of the growth of its surface. During this stage, the flame behaves as a piston, thus increasing the pressure and putting in movement the fresh gases in front of it. At a subsequent stage, flame propagation is dominated by the oscillating flow generated during this initial period.

Abstract #111

Unstable Explosion Flames and Acoustic Oscillations

D. Bradley, C.G.W. Sheppard, R. Woolley

Studies of instabilities in spherical gaseous explosion flames are described. It is shown that a decrease in Markstein number leads to large increases in the burning rate, particularly in the later stages of the explosion. The increase is associated also with the generation of strong acoustic oscillations. Experimentally, pressures were recorded during explosions of hydrogen - air and iso-octane - air at 0.5 MPa and different equivalence ratios. Burning velocities much higher than the laminar values were observed for the lean hydrogen and rich iso-octane mixtures. This is attributed to the rapid generation of a cellular flame structure, due to Darrieus - Landau instability. The interaction of pressure waves with the cellular structure can introduce further flame wrinkling through Taylor instability. Fan induced turbulence in the bomb showed that turbulence eventually suppresses such instabilities

Reciprocating Engines

Abstract #158

Three-Dimensional Modeling of DI Diesel Engine Combustion using a Flamelet Concept

Christian Hasse, Norbert Peters

Numerical simulation of diesel engine combustion has become an important tool in engine development. One major issue in modeling of turbulent reactive flows is the interaction of turbulence and chemistry. One successful way to model this

interaction is the use of the Representative Interactive Flamelet (RIF) model. The RIF model describes all phases of diesel engine combustion and therefore there is no need to use separate submodels for ignition or diffusive burning. It allows to use detailed reaction schemes which include submechanisms for all major pollutants such as NOx or soot. The RIF model has been recently extended to a multiple flamelet model which is called Eulerian Particle Flamelet Model (EPFM). Each representative flamelet is represented by an eulerian particle having its own time history. These particles are convected through the flow field and an equation for the probability of finding a particle at a certain location and time has been derived on the basis of a Pdf transport equation. Using multiple flamelets allows to account for spatial variations of the scalar dissipation rate which is especially important during the ignition phase. We present results for a direct injection diesel engine. In addition to a general discussion we focus on various new aspects of interest which include the homogenization of the flow field and its effect on transport processes in the flamlet and the effect of vaporization in the balance equation of the mixture variance which shows to have an important effect on the scalar dissipation rate.

Abstract #85

Application of Pulsed Flame Jet to Compression Ignition Premixed Charge Engine

Eiichi Murase, Kunihiko Hanada, Takatsugu Katayama

In diesel engines, most of the fuel is burned in a diffusion combustion phase, which inherently leads to the formation of excessive amount of soot and NOx emissions. In order to decrease soot and NOx emissions simultaneously, the concept of lean premixed compression ignition engine has been proposed. The onset of the combustion of this engine depends on the autoignition of the fuel, so it is quite difficult to control the ignition timing. On the other hand, it has been revealed that Pulsed Flame Jet (PFJ) has a great potential to enhance ignition reliability and burning rate in lean mixtures. In PFJ, the combustion is initiated in the jet issuing from the igniter, that is, the combustion is initiated volumetrically. This volumetric combustion initiation must behave as a trigger for the autoignition of the fuel in the combustion chamber. In this paper, autoignition characteristics of n-butane in the rapid compression machine (RCM) were shown first. The appearance of low temperature flames was observed in autoignition of n-butane in the RCM used here, and it was realized that the final compression conditions in the RCM correspond to the positive temperature dependence region. Then the combustion tests with PFJ were carried out and it was demonstrated that the onset of combustion can be controlled by PFJ, and it was revealed that PFJ has a potential for the ignition timing control of the compression ignition premixed charge engine.

Poster Session I

Abstract #11

Formation of Nitric Oxide in a Multi-Staged Air LPG Flame

Han Seok Kim, Seung Wook Baek, Myoung Jong Yu

In this study, a numerical simulation was developed which was capable of predicting the characteristics of NO formation in pilot scale combustor adopting the air-staged burner flame. The numerical calculation was constructed by means of establishing the mathematical models for turbulence, turbulent combustion, radiation and turbulent nitric oxide chemistry. Turbulence was solved with standard k-ε model and the turbulent combustion model was incorporated using a two step reaction scheme together with an eddy dissipation model. The radiative transfer equation was calculated by means of the discrete ordinates method with the weighted sum of gray gases model for CO2 and H2O. In the NO chemistry model, the chemical reaction rates for thermal and prompt NO were statistically averaged using the β probability density function. The results were validated by comparison with measurements. For the experiment, a 0.2 MW pilot multi-air staged burner has been designed and fabricated. Only when the radiation was taken into account, the predicted gas temperature was in good agreement with the experimental one, which meant that the inclusion of radiation was indispensable for modeling multi-air staged gas flame. This was also true of the prediction of the NO formation, since it heavily depended on temperature. Subsequently, it was found that the multi-air staged combustion technique might be used as a practical tool in reducing the NO formation by controlling the peak flame temperature.

Abstract #39

Triple Flames Around Two Droplets in Flows with Fuel Vapor

Wei-Hsin Chen

Flame structures around two equal-sized and interactive fuel droplets in high-temperature flows are examined by means of a numerical method in which a body-fitted technique in association with non-orthogonal curvilinear coordinate is employed. For the two-droplet system, the leading droplet versus the trailing one intrinsically acts as a fuel vapor source. Therefore, when the fuel is vaporized from the leading droplet and then brought to where near the trailing one, a situation of non-uniform mixture is exhibited. Under such a situation, when the gas-phase combustion is excited, while the flame is stabilized between the two droplets as a consequence of another role played by the bluff body of the leading droplet, an anchor-shape flame structure, i.e. the triple flame, is observed. In this flame, three different combustion modes including fuel-lean, fuel-rich, and stoichiometric burnings are simultaneously observed. When far-field temperature or ambient equivalence ratio is increased, because flame speed is enhanced, the flame

propagates upstream and the fuel-lean premixed flame withers. However, if the ambient equivalence ratio is as high as 0.2, it is obvious to find that two wings of the triple flame, viz. the fuel-lean and the fuel-rich premixed flames, extend outward from the stoichiometric point. Once the flame encloses the leading droplet, the triple flame evolves into a double-flame consisting of a fuel-lean premixed flame and a diffusion flame. Accordingly, the obtained results elucidate that both upstream temperature and fuel vapor concentration play a vital role on the two droplets, vaporization rate and flame structure.

Abstract #179

Radiant Ignition Models for Nitramine Propellants

A. Cohen, K. L. McNesby, R. A. Beyer, R. Wainner

The ability of radiant propellant ignition models to predict initial pressurization rates in gun chambers is a prime requirement for interior ballisticians. Phenomenological models use global kinetics for condensed phase energy production rates of the propellant materials. These can be used to predict ignition delays but not pressurization rates. Recent physical radiant ignition (and combustion) models for nitramine propellants consider detailed chemical kinetic mechanisms for condensed and gas phases. These models are capable of predicting temporal variations in temperature, pressure and. chemical species. Validation of these models can be made by comparing predictions with measurements of emission delays (first light), pressurization (delays and initial rates) and transient appearances (and concentrations) of gaseous products. This paper will present recent results of an investigation of CO2 laser ignition of pressed pellet samples of neat RDX (cyclotrimethylene trinitramine) and samples cut from extruded strands of XM39, a heterogeneous gun propellant containing approximately 75% RDX in an inert binder (cellulose acetate butyrate). Experiments were conducted in a windowed chamber at atmospheric pressure in air and N2 with flux densities = 10 - 200 cal/cm2-s and pulse length < 2s Wave-length integrated emission from the plume generated near the surface of the samples were recorded with photomultipliers (wave length = 300-800 nm response). Simultaneous records of emission from excited OH and CN species were obtained using interference filters (wave length = 310 and 388 nm, respectively). A CCD/spectrometer (Princeton Instruments) was used to record emission spectra (wave length = 250 - 850 nm) integrated over various time intervals during (laser assisted flame) and after (unassisted flame) the laser pulse. These were used to identify the various species produced during ignition. Transient pressure was measured with a piezoelectric transducer. Comparisons of measurements with predictions of phenomenological and physical radiant ignition models (1-D) will be presented.

Abstract #93

A Thermochemical Code (TDS) for Thermodynamic Calculations of Complex Chemical Systems

S.A. Gubin

The TDS code can compute steady-state thermodynamics problems with two assumed constant parameters (TV, TP, UV, HP, SV, and SP problems) and stationary gas dynamics problems (Chapman-Jouguet detonation, incident shock wave). The TDS software is designed to perform thermodynamic calculations of compositions and characteristics of complex chemical systems described by various equations of state under phase-equilibrium and prescribed nonequilibrium conditions. The TDS can be used to calculate the thermodynamic equilibrium for a complex chemical system of an arbitrary elemental composition. Both starting reactants and reaction products can be multicomponent and/or multiphase systems consisting of substances in different phase conditions. Thermodynamic properties of pure condensed phases can also be calculated by using various EOSs. The software package incorporates data banks of caloric properties for many individual species and data bases containing parameters of thermal equations of state (EOSs) for gaseous and condensed phases of several types. Computer code TDS is intended for thermodynamic modeling of properties of complex multi-component and multi-phase chemical systems under high pressure and temperature. In particular, TDS allows to carry out calculations of HE detonation parameters with several EOS of detonation products, including theoretical models based on realistic potentials of molecular interactions and methods of statistical mechanics. So, thermodynamic perturbation theory and the integral equation method based on the Exp-6 intermolecular interaction potential are used to obtain reliable predictions of fluids properties in broad temperature and pressure ranges. These equations are also employed in computing detonations in condensed systems.

Abstract #213

Experimental and Theoretical Investigation of Low Temperature PAH and Soot Formation on Hydrocarbon Flames

B.A. Urmashev, T.T. Mashan, B.Ya. Kolesnikov, Z.A. Mansurov

This paper presents the study of polycyclic aromatic hydrocarbons (PAH) and paramagnetism of soot particles sampled from cool sooting flames of methane and propane in a separately-heated two-sectional reactor under atmospheric pressure at the reactor temperatures of 670-1170 K. The temperature profiles of the flames were studied. The sampling was carried out with a quartz sampler and the samples were frozen with liquid nitrogen. A number of polyaromatic hydrocarbons such as pyrene, fluorantene, coronene, anthantrene, 1,12-benfherylene, were identified by spectroscopic methods in the extract of soot. In order to explain

experimental results we have performed numerical model of formation PAH at burning of methane. The accounts kinetics of burning of methane on a basis of kinetics scheme was executed. For accounts previously were designed a molar heat of formation of intermediate connections and are picked up kinetics of elementary constant reactions.

Abstract #120

Effects Of Variable Density On Mixing Effeciency In Axisymmetric Turbulent Confined Jets

N. Belaradh, B. Sarh, J.N. Blanchard, I. Gökalp

The turbulent flows where the density strongly varies occur in various industrial applications, related on energetics and propulsion. This type of complex flows (strong coupling between dynamic and scalar fields), were studied within the framework of many numerical and experimental work. In the present study, the objective is to isolate and analyse the main physical mechanisms governing the development and the structure of the jet and the efficiency of mixing. The continuity, momentum, mass fraction and turbulence equations are solved using the finite control volume methode for two dimensional elliptique flows. The results are presented for differents velocity ratios, m=Ue/Uj, and density ratio, Rr=re/rj, where re and Ue are the density and velocity of the coflow and rj and Uj are the jet density and jet velocity. The efficiency of mixing of mass originating from the jet with coflow is studied for varying Rr. Finally, the comparisons with measurements are presented and discussed.

Abstract #116

Towards a Generalized Level-set/in-cell-reconstruction Approach for Accelerating Turbulent Premixed Flames

Heiko Schmidt, Rupert Klein

Due to the feedback between turbulence, gas expansion and flame front dynamics a continous acceleration of premixed flames can occur. This process occurs, e.g., in large scale gas explosions and astrophysical nova- and supernova explosions. In the context of flame accelerations and DDT one is faced with rapidly changing thermodynamic, mean flow and turbulence conditions. One consequence is that the internal structure of the propagating combustion front will become inherently time dependent. In addition, the turbulence intensities associated with the accelerating flow will increase and grow rapidly beyond the characteristic burning velocity of a laminar flame. While turbulence intensities are still low, quasi laminar combustion takes place in thin "flamelets". Turbulent combustion modelling will in this case aim at a description of the net flame surface area and of the mean quasi-laminar burning velocity in order to arrive at the net rate of unburnt gas consumption. If, on the other hand, turbulence intensities increase dramatically, then the turbulence-induced strains will locally distort the flamelet structures or even quench them completely and a more stochastic interaction between reaction, turbulent transport and

diffusion becomes significant. As a consequence in these regimes, the "thin-rection-zone regime" and the "well-stirred reactor" regime, very different effective turbulent combustion models must be employed. Here we present a new numerical technique which—given such a set of (turbulent) combustion models—allows us to consistently represent laminar deflagrations, fast turbulent deflagrations as well as detonation waves. Supplemented with suitable DDT criteria, the complete evolution of a DDT process can be implemented in principle.

Abstract #41

Concept of the Limit of Existence of 2-D Steady-State Structure of Fuel Liquid Film under Flame Propagation

Oleg V. Sharypov, Konstantin A. Medvedko

Two-dimensional steady-state structure of the flow in fuel liquid film on heat conductive substrate under combustion wave propagation is theoretically studied in the framework of hydrodynamic approach. Physical mechanisms of the structure forming are analyzed. It is shown that the important role belongs to thermocapillary effect. The conclusion that two-dimensional regime is possible only when the value of temperature gradient at the film surface is low enough is substantiated. The critical condition governing the transition to three- dimensional regime is derived. This condition means the balance between the velocity of the flow (induced for example by gravitation) and the velocity induced by thermocapillarity. If the temperature gradient exceeds certain critical value then the zone with reverse flow would appear according to 2-D model. In the previous works we suppose that such regime could not exist because of its instability relatively to 3-D perturbations. Indeed, the experiments with flowing liquid films upon immovable local heat source (without combustion wave) confirm the conclusion about the transition to 3-D regular flow structure when the temperature gradient is high enough. The first part of the paper is devoted to modeling 2-D film structure in critical regime. The second part of the paper deals with generalization of the problem to the case of heat source, moving with constant speed. This statement of the problem includes the flame propagation. Mathematical formulation of this problem allows us to conclude that existence of 2-D solution in this case is limited by the same condition. If the temperature gradient is more than critical then 2-D film structure would not exist. This concept substantiated at the present work explains the phenomena experimentally observed in liquid films under local heating.

Abstract #32

Modeling of Natural Gas Reburning Process with Pressure Pulsations

L.Szecówka, R.Jarnicki, A.Teodorczyk

Reburning is a very complex process, containing heat and flow phenomena connected with chemical kinetics. Having in mind that many researchers underlined the role of mixing we decided

to intensify mixing by introduction of pressure pulsations. Our previous experiments have confirmed the influence of generated pressure pulsations on mixing of reactants and their combustion. Further studies have revealed the influence of pulsations on emissions of NOx and CO), and other on spatial location of CH and C2 radicals in disturbed flame. These observations were used in further experiments consisted in cold and hot model tests. In the next stage the simulation model was developed of the process of reburning with pressure pulsations. The primary combustion products of fixed chemical composition from the main burner are flowing into the reburning zone, where mixing with additional reburning fuel (natural gas) occurs. Mixing process proceeds in natural way or it can be assisted by pressure pulsations. Numerical simulations were performed with the use of KIVA3V code with detailed chemistry model for natural gas combustion. The model was prepared with the use of CHEMKIN program and consists of 34 chemical species and 170 reactions. The results of this study confirmed the lowering of NO concentration in combustion products after introduction of pressure pulsations to the reburning zone. The increase of amplitude of disturbance intensifies the process of mixing of reburning fuel with primary combustion products, which results in higher reduction of NO concentration.

Abstract #149

Burning Intensity of Laminar Premixed Flame with Continuous Changing Stretch Rate along the Flame Surface

Takeshi Yokomori, Masahiko Mizomoto

A relation between the burning intensity and the continuous changing stretch rate along the flame surface was experimentally investigated. The flame temperature and the flame stretch rate along the flame surface were measured for the flame with continuous convex and concave curvatures (we call 3V-type) and for one with a single convex toward the fresh mixture (V-type), which were formed in the laminar flow of the lean propane/air mixture (f=0.72, Le=1.82). As a result, the flame stretch rate for 3V-type was equal to one for V-type everywhere except the location near the concave, so that those flames were equal in the flame temperature which was estimated from the theory proposed by C. J. Sun et al. However, measured flame temperatures were not the same between 3V and V-type. We guess the reason why such difference was arisen is the existence of the heat transfer along the flame surface, and we suggest that the heat transfer along the flame surface should be considered in the theory proposed by C. J. Sun et al.

Abstract #134

Numerical Modeling of Detonation Properties for Cast TNT

Juzhen Cao, Shurong Zhou, Longhe Liang

Referring to the data of reaction rate and JWL equation of state reported by Lee, E. L. and Tarver, C. M., we compute the

detonation wave structure and numerically simulate the shock initiation and detonation proceeding around a corner of cast TNT by using the 2D Lagrangian FCM code. We also compare the results obtained from computation with those given by experiment, and find both of them well agreeable with each other.

Abstract #52

To the Theory of Ignition and Detonation of Coal Particle Gas Mixtures

A.Fedorov, T.A. Khmel', Yu. A. Gosteev

The urgency of the problem of coal - gas mixture ignition and detonation is caused by this medium wide use as fuel mixture in power facilities and by the problems of the combustion and fire safety in coal-mining and power industries. The mathematical model of ignition of a multicomponent coal aerosuspension is presented within a point-wise approach of mechanics of heterogeneous media. The problem of coal - gas mixture ignition behind a reflection shock wave is solved as an application. The distinctive variants of the mixture thermal history realized under various proportions between relaxation times of nonequilibrium processes are shown: heterogeneous ignition due to coke oxidation reaction, homogeneous ignition by means of gas phase volatiles matters reaction, hybrid ignition due to coke and volatile matter oxidation processes simultaneously. The model verification is realized using the experimental data relating to the ignition delay times of the mixture of the coal particles with air and oxygen under conditions behind reflecting shock wave. The second part of the paper is devoted to the problem of mathematical modelling of detonation processes in coal particle - gas mixtures. The model of detonation of small coal particle aerosuspension is developed taking into account processes of pyrolysis, coal volative matter combustion, and coke combustion. The model is verified by experimental data on the dependence of detonation velocity on initial particle concentration. The stationary detonation structures are analyzed.

Abstract #130

Numerical Modeling of Unstable Detonation in Heptane Vapor-Air Mixtures

Tao Hong, Qin Chengsen

Unstable detonation in heptane vapor-air mixtires is numerically modeled by using three step chemical mechanism with two reversible reactions. The ignition condition is the gas with high velocity and high temperature. Three kinds of solution are obtained. First, as the velocity of ignition gas is slow the detonation fails to develop. Second, the pressure histroy becomes double oscillation after several single oscillations. The last is much comple solution that pressure is very irregular.

Abstract #75

Numerical Study of Detonation Instability for a Two-Step Kinetics Model

K. Mazaheri, S.A. Hashemi, J.H.Lee

In parallel with linear stability analyses, there have been numerous studies concerned with the numerical simulation of the pulsating detonation instability with Arrhenius one-step reaction kinetics. In one-dimensional calculations, the detonation instability appears as oscillatory behavior of detonation front. Using advanced numerical techniques, simulations of reactive Euler equations were able to obtain numerical results in close agreement with the theoretical predictions. Previous research have shown that for one-step Arrhenius kinetic model the activation energy is the main parameter, which determine the instability of CJ detonation. In one-step model, for a mixture with Q/RTo=50 and gamma (the specific heat ratio)=1.2 the ZND structure is unstable for Ea/RTo higher than 25. In this paper a two-step reaction model is used to study the stability of detonation. The first step is a non-heat release induction step and the second one is an exothermic reaction. The effect of activation energy on the detonation front behavior has been studied in this work. In our calculations, Q/RTo=50 and gamma=1.2 are used. It is observed that increasing activation energy of induction step (Ea1), destabilizes a detonation, the same behavior as one-step model. Increasing Ea2 (i.e. the activation energy of the heat release step), has a stabilizing effect for Ea2<25, that is the stability limit of one-step reaction model. Increasing Ea2 to value higher than 25, has a destabilizing effect. It seems that increasing the difference of two activation energies, (i.e., Ea1-Ea2), tends to destabilize the front propagation for Ea2<25. The same result was reported by Sharp for pathological detonations regardless the value of Ea1 or Ea2.

Abstract #228

Thermophysical Properties for Dense Multicomponent High Temperature Media

G.A. Pavlov

The investigations of a matter with significant interparticle interaction (a non-ideal matter) are progressing rapidly due to the development of prospective technical projects, combustion and explosion problems modelling. The design of new technology devices and the necessary modeling of high energy density combustion and explosion phenomena assume the knowledge of the thermophysical properties of a high temperature dense matter. These properties include: thermodynamical, transport, optical and rheology characteristics of dense matter. Complete thermodynamic analysis of the thermodynamical model of real non-ideal high temperature matter is provided. The model approaches to the calculation of the total set of non-ideal matter transport coefficients, optical and rheology properties of a matter are discussed. It is discussed, in general, the situation at the Burnett

level which can arise in combustion problems. The realization of the models for the determination of thermodynamic properties, the total set transport coefficients, optical and rheology properties of a multicomponent high temperature dense matter as the computer codes complex, calculations of the thermophysical properties of practically important substances and mixtures has permitted one to consider a number of high-temperature topical problems.

Abstract #19

Generation of Particle Clouds by means of Pressurized Gas and Gas Generators

Helmut Schneider, Norbert Eisenreich

The controlled release and dispersion of µm sized particles into the surrounding atmosphere is of interest in several research projects at ICT: further development of fuel air explosive systems for conventional application and eventually as a defence system against B- and C- weapons, non-lethal weapons systems, investigation of dust explosions and development of fire extinguishing systems. Dependent on the type of application a particle cloud with special geometry and particle concentration within the cloud should be generated within a short time scale of a few milliseconds to about 100 ms. The basic idea is a realization by means of gas generators. These can be tailored for the special application with respect to for example burning velocity, -temperature, and gas output; together with an appropriate design of the mechanical construction the generation of a well-defined cloud seems to be possible. Since there has to be done a large number of tests to clarify the correlation between the components of the whole system, tests have to be made on a small scale; however, since the dispersal of a large amount of mass may be different, tests on a realistic scale are also necessary. This paper reports on pretests with pressurized gas systems on two different scales. The initial pressures for the dispersal of masses in the range of 0.32 kg to 2.52 kg were 5 MPa and 10 MPa. The modeling of the propagation of the cloud with respect to geometry and volume can be achieved by simple assumptions.

Abstract #226

Combustion and Explosion of Condensed Reactive Systems as Result of Thermodynamics Stability Loss. New Ideology and Aspects

O. Shlensky

Every condensed volatile or nonvolatile substance, including explosives, has an upper temperature boundary of their existence in the metastable state, i. e. the spi-nodal line. The spinodal line zone may be approach under intensive heating or another high-energy action. Near the spinodal every condensed reactive system transmutes into labile (unstable) state, i.e. it will be collapsed. The self-accelerate combustion and explosion processes we consider as result and development of thermodynamics stability loss which accurse near spinodal line.

The spinodal zone may be approach with intensive heating during process of ignition, steady-stable combustion front propagation processes. This communication summarized the many years experimental and theoretical study of upper metastable phase state boundary (spinodal) and the specific pre-spinodal effects which take place near this boundary. Present day theory of combustion and explosion has been elaborated for the gas phase only, which has neither spinodal nor spinodal collapse. Therefore, the gas theory does not take into consideration any pre-spinodal physical or chemical effects (spinodal limitations of any physical properties: density, coductivity, and heat capasity). Mathematical models of Gas theory are especially invalids in the vicinity of the spinodal line. The new concept suggested overcomes this drawback and provides correct and adequate to physical nature new mathematical models for condensed reactive systems transformation. New relationships are developed, particularly, for thermal conduction equation, heat release function, adiabatic ignition delay period of self-ignition etc. They allow to make more precise the calculations and describing of combustion and explosive processes of condensed reactive systems.

Abstract #105

Thermodynamics of Propane-Air Composition Detonation in the Mixture with Hot Detonation Products

V.V.Vlasov, V.A.Ogarkov, V.I.Tarzhanov

Thermodynamic calculation program for parameters of detonation in gas mixtures is developed and implemented in the «Borland C++» package. Algorithm is based on the system of equations, which couples the state of gases prior to and after the detonation wave. Prior to the detonation wave these gases include mixture of the gaseous fuel, an oxidizer (oxygen or air) and explosion (combustion) products. After the wave passage they include all substances found in noticeable amounts in the temperature range of 220-5500°K;. Detonation parameters for stoichiometric propane-air compositions in the mixture with hot detonation products (HDP) are calculated. These mixtures are experimentally studied at TSD-01M facility. Nontrivial result is that detonation limits of examined mixtures with hot detonation products were discovered to expand with the increased content of the latter. Abnormally great increase in the upper limit of detonation is obtained with more than 80% content of hot detonation products. Of interest is the significant pressure drop in the Jouget point as well as the drop in caloricity of mixtures with increasing concentration of hot detonation products. Temperature of mixtures remains high and is the dominant factor of their detonability at high concentration of hot products. The results are rather important as the forecast for experimental setup and have heuristic value in the general challenge of spontaneous detonation occurrence in fuel-air clouds of emergency industrial releases.

Abstract #33

Quenching of Gas Detonation in Tube by Injection of Inert Gas

A.Dabkowski, A.Kozak, A.Teodorczyk

The effectiveness of an inert gas or fire-fighting agent in suppressing detonation can be rated by the extent to which it decelerates the propagating wave and simultaneously attenuates the hazardous shock wave, which is always ahead of the flame in the decoupled quenched detonation. The objective of this study was to examine the influence of inert zone created dynamically prior to ignition in combustible mixture on detonation propagation and attenuation. Four inert agents: He, Ar, N2 and CO2, and one fire inhibiting agent: C4F10 (FC3110), were used in the experiments. The effectiveness of all suppressants under study was evaluated on the basis of performance parameters defined as the ratio of velocity and pressure reduction in comparison with baseline case of non-inhibited detonation. It was shown that injection of inert gas can be an effective method of suppressing detonation in tube. In this study the critical conditions for detonation attenuation for different inert gases were determined. It was found that effectiveness of inert gas increases with its molecular weight.

Abstract #10

Modeling of Turbulent Spray Combustion under Cryogenic and Elevated Pressure Conditions

D. Schlotz, M. Brunner, E. Gutheil

The paper concerns the modeling of turbulent liquid oxygen/hydrogen spray combustion for elevated subcritical pressure and cryogenic inlet temperature conditions. In particular, the combustion in the single injector combustion chamber is modeled where experimental data are available for gas phase temperature and both droplet size and velocities. The model uses an Eulerian-Lagrangian formulation for the gas and the liquid phase, respectively. Detailed models for droplet heating and vaporization in a convective flow field are employed, and detailed gas phase reactions are accounted for through use of a flamelet model for turbulent spray combustion. The results show a very good agreement between experimental and computational spray characteristics. The computed gas phase temperature lies somewhat above the experimental values which is associated with CARS single shot measurements and incomplete data for the initial conditions of the combustion process.

Shock Interactions

Abstract #187

Simulations of Shock-Induced Mixing and Combustion of an Acetylene Cloud in a Chamber

John B. Bell, Marcus S. Day, Vincent E. Beckner, Allen L. Kuhl, P. Neuwald, H. Reichenback

In this paper we present numerical simulations of the interaction of a blast wave with an acetylene bubble in a closed

chamber. We model the system using the inviscid Euler equations for a mixture of ideal gases. The formulation specifies the thermodynamic behavior of the system using a Chemkin interface and includes the capability to model combustion as the ambient air mixes with the acetylene. The simulations are performed using a three-dimensional adaptive mesh refinement algorithm based on a second-order Godunov integration scheme. Simulations are compared with experimental measurements for the same configuration.

Abstract #171

Visualization of Blast Waves in the Early Stage of Milligram Charge Explosions

Toshiharu Mizukaki, Harald Kleine, Masahide Katayama, Kazuyoshi Takayama

In this paper, early stages of silver-azide pellet ignition by the irradiation of pulsed ND:YAG laser was quantitatively investigated. As in particular the shape of shock waves at very early stages was strongly affected by the orientation of cylindrical pellets and also the point on which the laser beam irradiated. In order to identify the early shock shapes, direction indicating color schlieren method was applied, in which the delicate variation of hue corresponds to the direction of density gradient in the test field. Cylindrical pellets were ignited either by direct irradiation of laser beam in air or by attachment on an optical fiber through which pulse laser beam was irradiated. The optimized orientation of the beam irradiation and also the direction of observations were very precisely determined. The effect of the pellet shape on shock wave formation was investigated numerically. In the series of experiments, 0.5 mg silver-azide pellets having slightly irregular shape were ignited again by the laser beam irradiation through the optical fiber and the motion of shock waves were visualize by schlieren method with IMACON468 high-speed camera. Numerical comparison was carried out using AUTODYN-2D and the result agreed reasonably well with the result of visualizations. Very minute structures of jet formation from micro-explosives and induced shock wave were resolved.

Dusty Shocks/Detonations

Abstract #14

On Modeling of Shock Waves Interactions with Combustible Dusty Gas Layers

R. Klemens, P. Wolanski, P. Kosinski, V.P. Korobeinikov, I.V. Semenov, V.V. Markov

Physical processes of coal dust/air mixtures motion, ignition, and combustion behind shock waves are numerically studied. Mathematical modeling methods are used. The moving medium is treated as two-phase, two-velocity and two-temperature continuum with mechanical and thermal interaction between the phases, and taking into account extraction of volatiles from particles, gas-gas and gas-particle exothermic chemical reactions, viscosity, diffusion, radiation

and heat conduction. In the paper we focus on two aspects of the problem on unsteady processes behind shock waves propagating in a gas over dust layers. The first one concerns the dust entrainment and dispersion from the dust layer behind a shock wave in a tube or a gallery. In this paper we simulate the particle lift and dust dispersion from the thin layers near walls by taking into account lifting forces due to particles rotation and gas vorticity. The second aspect is ignition and burning in a gallery of arising two-phase mixture. It was shown by calculations that temperature of mixture is high behind the shock and burning process takes place for shock Mach number equals to 3 (or grater than 3). The results of the calculation are demonstrated in Figures and diagrams. The comparisons of the results with available experiments are briefly discussed.

Abstract #54

Shock and Detonation Wave Propagation Along Reactive Particle Cloud in Channel

A.V. Fedorov, T.A. Khmel'

Shock and detonation wave propagation in a channel partly filled with a cloud of solid reactive particle aerosuspension is investigated. A plane shock wave propagating along the channel is considered as an initiation factor. The problem in studied on the basis of numerical modelling of two-dimensional two-phase reactive media flow. Te calculations show that the SW reflection of the plane of symmetry can be regular or with the Mach stem appearing. If the relaxation zone widths are comparable with the transverse cloud size then the reflected shock wave adjoining to the Mach stem is smeared. The particle cloud behind the passed SW is compressed in transversal direction. The region of the flow turning has a triangular shape. The vortex structure leads to the cloud spreading. At strong incident SW the particles ignite and combustion zone appears generating a transversal shock wave. The transversal shock wave propagation and reflections lead to the leading shock wave periodic fluctuations. A combined shock/detonation wave developing takes place in the channel. The shock wave in gas joining with the wave of heterogeneous detonation in the particle cloud propagates in quasistationary regime.

Multi-phase Combustion I

Abstract #142

Control of Single Droplet Combustion and Emission

S.M. Frolov, V.S. Posvyanskii, V. Ya. Basevich, A.A. Belyaev, O. Esmilaire, C. Jablon, P. Schmelzle

The ultimate objective of the research summarized in this paper is to compare combustion and pollutant-emission performances of pure-fuel and emulsified-fuel droplets. The paper describes the mathematical model of droplet combustion and the results of its implementation. As an example of a heavy hydrocarbon fuel and volatile component, n-tetradecane and water were used. Fuel-water emulsion of this type simulates the performance of Aquazole - a new emulsified fuel for heavy-duty diesel engines. It has been shown that addition of a volatile

liquid component to a hydrocarbon fuel allows one to control droplet combustion and emission performances by decreasing the amount of fuel vapor accumulated between the flame and the droplet surface and displacing the flame closer to the surface. As a consequence, more intense interphase fluxes occur, affecting the droplet lifetime and pollutant emission. The main distinctive feature of the emulsion droplet gasification is the existence of a relatively long (up to 80% of the droplet lifetime) period of droplet expansion due to formation of steam bubbles in the droplet interior. The predicted overheat of steam bubbles attains 100-150 K. Gasification of a single emulsion droplet of diameter d exhibits a fast stage of droplet surface regression after passing the maximum in the 'd-squared - time' curve. This stage can be conditionally treated as the microexplosion stage. Combustion of fuel - water emulsion droplets was shown to exhibit significantly less soot and nitrogen oxide emission indices as compared to pure-fuel droplets.

Abstract #83

Oscillations in the Flame Speed of Globally Homogeneous Two Phase Mixtures

F. Atzler, F.X. Demoulin, M. Lawes, Y. Lee

The combustion of clouds of fuel droplets is of practical importance in gas turbines, diesel and spark ignition engines, furnaces and hazardous environments. Under certain conditions, spherically expanding spray flames, following spark ignition, exhibit strong periodic fluctuations in flame speed which, are not acoustic in origin. These pulsations can significantly affect the burning rate and are not yet understood. In the present work, the combustion of initially quiescent premixed sprays was experimentally and theoretically investigated. Sprays were generated, thermodynamically, in an optically accessed combustion vessel by the Wilson cloud chamber technique. Centrally ignited explosions were observed by high speed Schlieren photography to yield flame speeds and oscillation characteristics. The affects of overall and gaseous phase equivalence ratio were studied for fuel droplet diameters up to 20 mm. It is shown that overall lean or stoichiometric mixtures with large liquid fractions were most likely to have pulsations in flame speed. A mechanism to explain the oscillations is proposed in terms of variations in equivalence ratio due to phase lags between flame and droplet velocities. These are due to droplet inertia within an accelerating flame. A model of this process is presented and results are compared with experiments. It is shown that, because droplets are initially stationary, the effective equivalence ratio is higher than that of the overall mixture. However, as the droplets accelerate, the effective equivalence ratio changes, which, in a feedback loop, affects droplet velocities such that it is possible for the flame to exist in an unstable, oscillating regime.

Abstract #211

Numerical Simulation of Multiphase Reactive Boundary Layer Flow by Mass Split Technique

Shou-Xiang Lu, Wei-Chen Fan

A comprehensive model of multiphase reactive boundary layer flow behind a shock wave is presented. Because of the multiphase reactions, the governing equations of the boundary layer contain source terms. As a result, the Leeds transformation which is valid to solve the problems of ordinary boundary layer can not be employed to solve the equations of the present boundary layer. Based on the view of the mass conservation, the gas can be divided into two parts. One part is the intrinsic part which is from the initial gas phase and another part is the extrinsic part which is generated during the process of multiphase reaction. And the concepts of extrinsic gas density and intrinsic gas density are defined to deal with the present boundary layer problem. The extrinsic gas density is the gas density increment due to the multiphase reaction in the boundary layer and the intrinsic gas density equals to the gas density of the boundary layer flow presuming without any chemical reaction. Therefore, the mass equation can be resolved to two mass equations, the extrinsic and intrinsic mass equations. According to the intrinsic mass equation, the flow function can be introduced as easily as the problem of ordinary boundary layer so that the Leeds-Dorodnitzyn transformation is valid for the present model. The sets of the equations adds one extrinsic equation after above transformed but the numerical solve for them become possible. In the present work, the numerical method for the laminar and turbulent boundary layer presented by Cebeci and Smith is employed. The Box scheme employed is of two order accuracy. To make a coupling of gas phase and solid phase equations, the method of Particle-Source-in Cell (PSIC) is modified because the PSIC method is based on the SIMPLER scheme which is constructed on the cells but BOX scheme on the junctions. The results by the present methods reveal the basic structure of the multiphase reactive boundary layer and give a good agreement with some of the experimental results. It is show that the present model is proper for the simulation of the phenomenon mentioned above.

Detonation Initiation I

Abstract #51

On The Controlled Generation and Detailed Observation of the Onset of Detonation

Richard Bambrey, Geraint Thomas

The detailed observation of deflagration to detonation transition (DDT) is inherently difficult due to the stochastic nature of the flame acceleration processes that lead to shock formation, which in turn gives rise to the conditions required for detonation to start. The paper describes how shock tube techniques have been used to generate the conditions required for the development of detonation in a more direct manner. The most detailed observations of the onset of detonation that are reported in the paper were obtained following the auto-ignition of stoichiometric ethylene-air diluted with 75% argon in the reflected shock region. After a further delay, in excess of a millisecond, local compression fronts were seen to form ahead of parts of the evolving turbulent flame. These then led rapidly to the onset of detonation. The paper will discuss the prevailing gasdynamic and thermodynamic state of the gas in the reflected shock region and how these may have contributed to the onset of detonation.

Abstract #180

The Influence of Local Disturbances on the Direct Initiation of Detonations

Hoi Dick Ng, John H.S. Lee

In direct initiation, experiments indicate that near the critical initiation regime, the onset of detonation originates from hot spots. Direct initiation appears to be a local event, yet initiation process is characterized by a single global parameter, i.e., critical energy of the source, which determines the overall transient flow field. To reconcile this dilemma, it appears that the critical blast wave decay is responsible to set the appropriate flow field for local hydrodynamic fluctuations to be amplified. The existence of a critical energy is to ensure that the blast wave generates a flow field appropriate for the rapid growth of hydrodynamic perturbations leading to the onset of detonation. Numerical simulations of the one-dimensional Euler equations with a three-step chain-branching reaction model are performed to study the influence of local disturbances on the direct initiation. The perturbation in density, reaction rate by free radical sensitization and chemical energy release are being investigated separately. The results shows that all these disturbances may lead to the formation of hot spots, which assist in triggering transition to detonation. The transition process for all disturbances is shown to be via a series of shock amplification, which appears to be the universal mechanism for detonation initiation. The nature of the perturbation that results in the hot spot formation is not important. Therefore, successful initiation depends globally on whether the initiation energy is enough such that the blast wave can set an appropriate

stage for these local disturbances to get amplified and trigger the onset of detonation.

Abstract #132

Diffraction and Re-Initiation of Detonations behind a Backward-facing Step

Shigeharu Ohyagi, Tetsuro Obara, Shintaro Hoshi, Pin Cai, Teruo Yoshihashi

Observations of diffraction phenomena of gaseous detonation waves behind a backward-facing step in a tube are performed by using a high-speed schlieren photography and soot-track record. Mixtures are stoichiometric oxyhydrogen mixtures and those diluted by argon at sub-atmospheric pressures. Three types of phenomena are observed, that is, continuous propagation of detonation, re-initiation after a temporal extinction of detonation and complete extinction of detonation. The re-initiation occurs at a wall surface of the tube behind a reflected shock wave. Positions and conditions of the re-initiation will be discussed.

Abstract #129

On Critical Conditions For Detonation Initiation By Shock Reflection From Rectangular Obstacles

Geraint Thomas, Simon Ward, Rhys Williams

A series of numerical simulations supported by experiments are reported on the interaction between a planar incident shock and a single rectangular obstacle. The dynamics of the interaction are described, particularly the reflection of the incident shock and the onset or otherwise of detonation. The test mixtures used were stoichiometric hydrogen and oxygen diluted with either argon or nitrogen, at an initial pressure of 5.3 kPa. The aim of the study was to determine the conditions under which a reflected detonation was generated. Predicted and observed critical conditions are compared with a simple criterion based on the auto-ignition delay time behind an ideal reflected shock and the acoustic transit time across the face of the obstacle. The physical and chemical processes that have been observed are also discussed.

Non-Ideal Detonations / Fast Deflagrations

Abstract #38

Photographic Study of the Transition Between the Quasi-Detonation and Choking Regimes

Daniel H.B. Lieberman, J.H.S. Lee

The range of boundary conditions in which a quasi-detonation transits to a high speed deflagration of the choking regime has been investigated. Quasi-detonations are characterized by velocities ranging from Vcj to about 0.65Vcj, while the combustion wave velocities in the choking regime correspond roughly the sound speed of the burnt products (i.e. 0.5Vcj). The experiments in the present study were carried out in a 4m long detonation tube which has an obstacle section located at the far end of the tube, (opposite the ignition source). Orifice and

perforated plates with blockage ratio (Br) = 0.45 & 0.55 were used in conjunction with πd, ∏d and 1d obstacle spacings. Mixtures with various argon dilutions were used to investigate the effects of cell regularity on the transition between the quasi detonation and the choking regimes. The results indicate that in orifice plate obstacles, the transition region occurs when L/l=2-3 where L is the distance between obstacles and l is the cell size. The obstacle geometry and percentage of argon dilution were also found to control the transition mechanisms. For argon dilution less then 75%, failure can be credited to the inability for transverse waves to develop. This failure mechanism is due to adiabatic cooling from the diffraction of the detonation over obstacles. For argon dilutions greater then 75%, failure results from excessive global curvature of the entire combustion wave front. Perforated plate geometries eliminate the transition completely and a smooth continuous decrease in wave velocity is observed. This suggest, that the perforated plate obstacles eliminate the shock diffraction and re-initiation mechanism as observed in the orifice obstacles.

Abstract #181

Propagation of Fast Deflagrations and Marginal Detonations in Hydrogen-Air-Additive Mixtures

A. Eder, F. Pintgen, F. Mayinger

The present paper reports on experimentally obtained results of fast propagating deflagrations, the transition-process from deflagration to detonation, and detonations in both hydrogen-air and hydrogen-air-additive mixtures. These combustion phenomena were investigated in a closed explosion tube (ID 66 mm, length 6.5 m) by means of various sophisticated conventional and optical measuring-techniques such as the color schlieren technique and the planar laser-induced predissociation fluorescence (PLIPF), which, in particular, gives a new insight into the understanding of these supersonic combustion-modes. Flame acceleration was provided by means of a periodic distribution of obstacles. Focus was put on the regime of the lean detonation-limit (marginal detonations). Within the obstacle path, it was observed that the maximum flame velocity depends strongly on the spacing of the obstacles. For an obstacle-spacing larger than 1.5 times the tube diameter, quasidetonations were observed for mixtures considerably less sensitive than required for the tube-diameter eq. cellwidth-criterion. In the unblocked tube section behind the obstacle-path, an onset of a spinning detonation mode was only observed for these obstacle configurations with a spacing larger than the tube diameter. For mixtures close to the detonability limit, it was also observed that the flame propagated as a fast deflagration with a velocity of 1000 m/s in the unblocked tube section up to the end of the tube. In this case, the highest pressure loading at the end of the tube (> 200 bar) was detected. For detonations close to the detonability limit, large pockets of unreacted gas were detected within the reaction zone by means of the PLIPF-technique.

Abstract #117

Slow and Fast Deflagrations in Hydrocarbon-Air Mixtures

M. Kuznetsov, V. Alekseev, Yu. Yankin, S. Dorofeev

Results of experiments on combustion behavior of methane, ethylene, and propane mixtures with air in obstructed tubes are presented. Critical conditions for development of fast deflagrations are studied. The tests are made in two tubes, 174-mm id and 520-mm id equipped with obstacles (blockage ratios equal to 0.3 and 0.6). It is found that similar to hydrogen combustibles two propagation regimes can be sharply distinguished: subsonic slow flames and supersonic fast flames. Critical mixture compositions for development of fast flames are determined in the tests. Critical conditions can be described in terms of a function of mixture expansion ratio on dimensionless effective activation energy (Zeldovich number). Critical values of expansion ratio increase with Zeldovich number. The results appeared to be in qualitative and quantitative agreement with our earlier studies for hydrogen mixtures. A significant effect of scale is observed for hydrocarbon mixtures in the rich side. The range of compositions, where fast flames are developed is wider in 520-mm tube, compared to that in 174-mm tube. The same effect was found earlier for hydrogen mixtures, but at smaller scale. An explanation for the effect can be based on relatively high flame thickness in rich mixtures of hydrocarbon fuels. Radiative heat losses may also play a role.

Abstract #28

An Experimental Investigation of Flame Deflagration Over Single and Multiple Solid Obstacles

S. Jarvis, G.K. Hargrave, S.S. Ibrahim

Experimental data is presented to describe the flame speed, flame structure and combustion chamber overpressure for flames propagating in premixed methane-air explosions in semi-confined enclosures. Data will also be presented to define the structure of the turbulent flow field generated ahead of the propagating flame in the wake of the obstacles using Digital Particle Image Velocimetry (DPIV). The role of turbulence is well established as a mechanism for increasing flame burning velocity by fragmenting the flame front and increasing the surface area of flames propagating in explosions. In the present experiments, the expanding flame pushes the unburned gas mixture ahead of the flame creating turbulence by vortex shedding into the wake of obstacles in the flow field. The flame interacts with the turbulent wake, increasing the flame surface area and the burn rate. The aim of the work is to quantify this interaction. To obtain the information required to quantify the role of obstacles, it is necessary to apply a range of sophisticated laser-based, optical diagnostic techniques. This paper describes the application of high-speed, laser-sheet flow visualisation and digital imaging to record the temporal development of the flame structure and Digital Particle Image Velocimetry (DPIV)

to define the turbulent flow field ahead of the propagating flame. The aim is to develop algorithms to define the structure of the turbulent flow field generated in the wake of obstacles in explosions and to provide experimental data for the development and validation of LES models for turbulent premixed flame propagation.

Effects of Acoustic Fields

Abstract #3

Analysis of Acoustic Wave Transmission through Turbulent, Premixed Flames

Tim Lieuwen

This paper describes an analysis of the characteristics of acoustic waves transmitted through turbulent premixed flames with moving, convoluted fronts that have random and possibly fractal characteristics. Such interactions play an important role in the characteristic unsteadiness observed in turbulent combustion processes that occur in a wide range of processing, power generating and propulsion applications. The problem is posed with an integral formulation of the acoustic wave equation and assumes that the smallest scales of flame wrinkling are much larger than the acoustic wavelength. Thus, these results apply to high frequency wave scattering. Solutions for the coherent characteristics of the transmitted field are derived in terms of the statistics of the flame surface height and its spatial gradient. It is shown that the important parameters controlling the characteristics of the coherent field are the wavelength and angle of the incident disturbance, the mean squared deviation of the flame surface from its average position, the mean squared slope of the flame surface, and the temperature jump across the flame.

Abstract #31

Flow Velocity Field in a Flame Submitted to Acoustic Modulations

Sebastien Ducruix, Daniel Durox, Sebastien Candel

Coupling of acoustics and combustion may lead to instabilities in many practical devices. The determination of the flame transfer function is then essential to the understanding of the phenomena. In this re spect, it is first natural to consider the case of a small scale burner before dealing with more complex systems. In the present experiment, a driver unit, placed at the bottom of a conical flame burner, creates a periodic modulat ion of the velocity at the burner exit. The frequency and amplitude of the acoustic modulation induce different resp onses of the flame stabilized above the burner. This configuration is used to determine the flame transfer function and compare it with an analytical model. The model relies on the relatively strong assumption that the fluctuating v elocity in the fresh stream is uniform and that its radial component is negligible. The aim of the present study is to measure the velocity field in the fresh gases and determine whether these assumpt ions are relevant and for what range of frequencies.

The experimental setup is first described. The modeling of the transfer function is briefly underlined and a comparison with experimental results for a particular case is proposed . The velocity measurements are then described and the velocity evolution during acoustic cycles is finally investig ated for different frequencies. The assumptions made in the modeling are justified for low frequencies, but they are too strong for larger reduced f requencies to correctly represent the acoustic-flame interactions. An improved model should take these features into account.

Abstract #61

Stabilization of a Non-Premixed Lifted Flame in an Acoustic Field

David Demare, Françoise Baillot

Main acoustic effects on a non-premixed lifted flame in the hysteresis zone are analyzed by means of visualization and velocity measurement techniques (high speed tomography, LDA, PIV). With no excitation, organized eddy structures due to jet instabilities (Kelvin-Helmholtz and secondary three-dimensionnal) act to stabilize the flame. Acoustics, changing some structures properties, can either improve or perturb both combustion and stability of the flame.

Abstract #224

Dynamic Characteristics of Kinetically Controlled Combustion and their Impact on Thermoacoustic Instability

Sungbae Park, Anuradha Annaswamy, Ahmed Ghoniem

Combustion in high performance engines utilizes strong swirl, recirculation and interacting jets to enhance the mixing rate of the fuel, air and products, and hence maximize the burning rate. The ideal limit for these systems is often modeled as a well-stirred reactor. The operation of a Well-Stirred Reactor (WSR) is governed by a characteristic residence time. Stable operation is achieved when the residence time is larger than the characteristic chemical time, otherwise blow-out should be expected. The condition under which a combustion system becomes unstable has been expressed in terms of the Rayleigh criterion, which states that a combustion system becomes unstable when the heat release increases at a moment of a rise in pressure. In a former study, we investigated the linear response of a WSR model to residence time oscillations using a single-step kinetics mechanism. We showed that as the mean equivalence ratio or the mean residence time approach the blow-out limit, the operating point may transition from stability to instability due to a sudden phase change between pressure and heat release oscillations. In this paper, we use the same approach with a multi-step kinetics mechanism instead of a single-step mechanism to examine its impact on the instability characteristics. We show that the phase between pressure and heat release oscillations changes continuously near the blow-out limit and that phase change depends on the perturbation frequency.

Plenary Lecture III

Abstract #P3

Formation of Nanoparticles in Gaseous Reactive Systems

Paul Roth

The synthesis of nanoparticles is an essential part of nanotechnology which is concerned with the development and utilization of structures and devices scaling between individual molecules and features below 100nm. Thin films, lateral structures, and very small particles are examples of nanotechnology. Nanoparticles are structures having a reduced size in all three dimensions which is called reduction from 3d toward 0d. Because of the large surface-to-volume ratio, quantum and boundary surface effects are becoming dominant. Therefore, nanoparticles have interesting properties compared to bulk materials including thermodynamic, magnetic, optical, electronic, chemical, and mechanical behaviour, which are only a result of their limited size. For the synthesis of nanoparticles various techniques are known which can be classified into colloidal (liquid phase) or aerosol (gas phase) systems. To the later ones belongs reactive aerosol synthesis which is very similar to combustion. It can - depending on the precursor material - proceed through a self-sustaining or pyrolysis type of reaction. Re- active gasphase synthesis of nanoparticles offers some advantages over material synthesis by other, e.g. wet chemical processes, mainly because of better product control such as particle size, crystallinity, degree of agglomeration, and chemical homogenity. The conversion of gaseous precursors to solid/liquid particles in a reactive gas flow is an exciting research area. The fundamental are not fully understood, especially the homogeneous gas phase kinetics, the particle growth and coalescence kinetics, and the early nanoparticle synthesis. The various mechanisms that can be found in gas-to-particle conversion include five basic steps which can proceed purely sequential or more or less interconnected are: (1) gas phase kinetics of precursors forming condensable species, (2) nucleation of supersaturated vapour forming clusters and early particles, (3) surface growth of primary particles by heterogeneous chemical reactions or by physical vapour condensation, (4) particle agglomeration by Brownian motion, (5) particle coalescence driven by the reduction in surface free energy. In the plenary lecture various examples for the different reactive gas-to-particle conversion steps will be demonstrated including shock tube kinetics of precursor reactions, flame synthesis of oxidic nanoparticles, heterogeneous gas/particle reactions, and formation of coated nanoparticles. A detailed understanding of underlying physico-chemical processes needs application of modern in-situ and ex-situ diagnostics for gas phase species and particles.

Detonation Initiation II

Abstract #138

A Planar Detonation Initiator

Scott I. Jackson, Joseph E. Shepherd

A planar detonation initiator has been developed using a specific geometry of channels to create a planar detonation wave. The device consists of a main channel off of which secondary channels extend perpendicularly. All secondary channels terminate on the same plane, opening into a common test section area. The channel lengths and geometry are such that initiation of a detonation in the main channel results in the wave travelling through each of the secondary channels, exiting them all at the same time. These separate detonation fronts then combine into a planar detonation front, which continues to propagate into the test section. This design is similar to one used for creation of a linear detonation front in high explosives. A CCD camera images the planar detonation wave propagating in the test section. Preliminary results from imaging and pressure trace data indicate that the device produces a nearly planar detonation wave for stoichiometric mixtures of ethylene and oxygen. Images of a reasonably planar wave have been obtained. Currently, the performance with stoichiometric mixtures of propane and oxygen is being investigated.

Abstract #143

Shock-wave and Jet Initiation of Gaseous Explosions

O.V. Achasov, O.G. Penyazkov

Some methods of initiation of gaseous detonation under non-steady flow conditions behind colliding shock fronts have been explored. The auto-ignition conditions are achieved using shock wave focusing and interaction of supersonic jets inside cylindrical cavity. Comparative studies of selfignition process behind incident shock waves reflected from cylindrical concave and plane walls in stoichiometric hydrogen-oxygen mixture revealed that the boundary between the strong and mild ignition modes coincides for the both types of reflection. For different initiation modes, the detailed evolutions of flow structure were studied using a high-speed schlieren photographic observation. To establish the mechanisms of transition from deflagration to detonation downstream of flow obstruction the runs were performed in a stoichiometric C2H2/O2 mixture with variable nitrogen dilution and at initial pressures varying from 0.02 to 0.1 MPa. It was found that critical shock strength corresponding to Mach number of M=1 of unburned gas flow venting into the pipe generates the necessary conditions to trigger the onset of detonation downstream of the orifice plate. For subsonic outflow of unburned mixture, the flame front overtakes the leading shock wave and detonation does not develop in observation region.

Abstract #55

Blast Waves Focusing In Hydrogen - Air mixtures

B. E. Gelfand , A. M. Bartenev , S.V. Khomik , S. M. Medvedev , A. N Polenov, L. H. Josephson, M. Banks

The phenomenon of blast waves focusing at non-flat reflectors (cone, wedge) in combustible hydrogen-air mixture was investigated experimentally. The blast waves in a shock tube were generated by the use of ultra-short high pressure chamber. The spherical blast waves were obtained from the detonation of 1 kg TNT charges.

Similar to the case of the focusing of the shock waves with uniform parameters behind the front, three regimes of selfignition in hydrogen-air mixtures were obtained: mild, transient, and strong. The critical Mach numbers of blast waves responsible for mentioned regimes of selfignition are very close to that obtained for the case of shock waves.

It was shown, that the shock tubes with ultra-short high pressure chambers can be used for the modelling of the specific features of shperical blast waves propagation in combustible gaseous medium.

Detonation Diffraction

Abstract #96

On the Mechanism of Transition of Self-Sustained Detonation from a Tube to a Half-Space Through an Annular Orifice with Central Obstacle

B. Khasainov, C. Priault, H.-N. Presles, D. Desbordes

Experimental and numerical study of critical conditions of detonation transition from a tube to a half-space through an annular orifice with central obstacle shows that the mechanism of transition to detonation is more complicated than it was thought before. Comparison of experimental and numerical soot traces shows that in a wide range of initial pressures the interaction of diffracted shocks on the axes of symmetry does not result in re-initiation of detonation. However, the implosion generates a super-detonation wave propagating along a thin layer separating the diverging curved shock and the front of associated decoupled flame. Curvature radius of this layer and its thickness are initially too small to re-initiate detonation in the fresh mixture during the super-detonation wave travel from the implosion point towards the basement wall and the flame again separates from the shock. During this travel the size of the bubble of reaction products escaping from the shock tube significantly grows. Reflection of the primary super-detonation from the basement wall initiates secondary super-detonation wave, which successfully ignites the fresh mixture and marks the layer between the shock and flame by very fine cells. Thus, the transition to self-sustained detonation is due to the interaction of the super-detonation with the basement wall.

Abstract #183

Critical Tube Measurements at Elevated Initial Mixture Temperatures

Gaby Ciccarelli

Experimental results obtained on the transmission of a planar detonation wave from a cylindrical tube into an unconfined volume are reported. Experiments have been performed using a 9.1 m long heated detonation tube connected to an 88.9 cm inner-diameter receiver vessel. Tests were performed using 10, 20 and 27.3 cm diameter tubes. The minimum, or critical, hydrogen concentration in air that results in detonation transmission into the receiver vessel has been measured at an initial pressure of 1 atm and for initial temperatures of 300, 500 and 650K. The value of the ratio of the tube diameter, d, and the critical mixture detonation cell size, S, was measured to be between 18 and 24. The data shows no correlation between the value of d/S and the initial mixture temperature and there is no observable effect of initial temperature on the cell regularity. The measured uncertainty in the average cell size was roughly ±25% which insufficient to explain the significant departure from the classical critical tube correlation d/S= 13. It is proposed that the d/Sc= 13 is not an unique, nor adequate, correlation for describing detonation diffraction in mixtures considered to have a regular or irregular detonation cellular structure.

Abstract #1

Self-Organisation of Multifront Structure in Extending Detonation Wave

Anatoly A. Vasil'ev, Anatoly V. Trotsyuk

The physical mechanisms of self-organisation of an ordered structure of detonation wave (DW) are discussed on the base of experimental investigations and numerical two-dimensional modeling of cylindrically expanding DW.

Practical Combustion

Abstract #166

Quenching Mechanisms of Gaseous Hydrocarbon-Air Flames in Packed Beds

T.A. Mihalik, J.H.S. Lee, G. Continillo, F.S. Marra

Objective of the present study is to investigate the phenomenon of flame quenching in a porous medium, by means of experimental data and of detailed numerical modeling, in order to assess the effect of heat losses on the extinction of gas flames in a porous medium, as compared to the effect of flame stretch induced by the flow. The quenching limits are determined experimentally as a function of the packed bed parameters, and the dependency is studied to elucidate the mechanisms of flame quenching in a packed bed of spherical particles. Numerical simulations based on a full Navier-Stokes 2D model are also used to separately test, via "ideal" experiments, the influence of each sub-mechanism. It is concluded that the quenching mechanisms in a packed bed are governed by those responsible

for more traditional flame quenching experiments with straight narrow channels. The dominant flame quenching mechanism in a packed bed of spherical particles is thus heat loss to the sphere surfaces by conduction.

Abstract #91

An Experimental Study of Venting Process of Gas-Air Mixture Combustion in a Cylindrical Vessel

Yikang Pu, Jun Hu, Fu Jia, Jozef Jarosinski, Jerzy Podfilipski, A. Zawadzki

Venting technique is popular and effective method to reduce the possible explosion damages of flammable gases, liquids or powders. The objective of the present study is to obtain basic information on flame development and pressure variation throughout venting processes for a cylindrical vessel with large aspect ratio (L/D=5.6) under various initial and boundary conditions. Both, constant volume and venting combustion experiments were conducted in a transparent cylindrical vessels of 1m long 0.18m in diameter made of perplex glass. High-speed CCD camera recorded the events at 500 frames per second and the data were transmitted to the storage. Three different vent diameters of 50, 80, 100mm were used in experiments. The ratios of vent area to the cross-section area of the vessel (d) were 7.7%, 19.7%, 30.8% respectively. The examined venting pressures were in the range of 0-0.18MPa, which is in agreement with safety engineering interests. The pressure development during the venting process is the consequent manifestation of two competing factors. One is the rate of gas production due to combustion, which is mainly determined by the flame surface and burning velocity. The other is the rate of outflowing gases from the vent, which is mainly determined by vent area and venting pressure. Numerical simulation was conducted for closed and venting vessel combustion. The predicted values of the maximum pressure in a closed and vented vessel appeared to be comparable with the measured magnitudes.

Shock Initiation / SDT

Abstract #22

Evolution of Stable and Pulsating Planar Detonations: Piston and Reflected Shock Initiation

Gary J. Sharpe

The process of planar detonation ignition and evolution, induced by a constant velocity piston or equivalently by a shock reflected from a stationary wall, is investigated using extremly long time, very high resolution one-dimensional numerical simulations. Previous work is extended to much later times. The overtake and merging of the detonation formed near the piston with the leading shock and the subsequent decay towards the steady state of the highly overdriven detonation produced by the collision are investigated. It is shown that the detonation may take many thousands of reaction times to approach the steady state, and shock waves resulting from large amplitude

gasdynamical disturbances produced in the collision of the detonation with the leading shock can overtake the front and upset the relaxation process. For cases where the steady state is one-dimensionally unstable, the shock pressure begins to oscillate with a growing amplitude once the detonation speed drops below a stability boundary. As the overdrive decreases, the detonation becomes more unstable as it propagates and the nature (e.g. period and amplitude) of the oscillations change with time. If the steady detonation is very unstable then the oscillations evolve over many tens of thousands of reaction times from limit cycle to period doubled oscillations and finally to irregular oscillations.

Abstract #123

Propagation Laws and Direct Initiation for Quasi-steady Curved Detonations with Chain-Branching Kinetics

Mark Short, John B. Bdzil

Propagation laws are derived for quasi-steady, near-CJ, weakly curved detonations for a chain-branching reaction model having two components. The first is a thermally neutral chain-branching induction stage governed by an Arrhenius reaction with a large activation energy, which terminates at a transition layer where conversion of fuel into an intermediate species (chain-radical) occurs. The second is an exothermic main reaction layer (or chain-recombination zone) having a temperature-independent reaction rate. For cylindrically or spherically expanding waves, a multi-valued detonation velocity-curvature relationship is found, similar to that found previously for a state-sensitive one-step reaction. The change in this relationship is investigated as the length of the main reaction layer is changed. We also discuss the implications that chain-branching reaction kinetics has on predictions of critical detonation initiation energy based on detonation-velocity curvature laws. Finally we conduct some calculations that illustrate the important effect that transverse flow variations may have on the quasi-steady propagation of nonplanar detonation fronts. Such variations may be important for the propagation of cellular gaseous detonation fronts and for the axial propagation of detonations in a cylindrical stick of condensed phase explosive.

Abstract #118

Investigation of Lateral Effects on Shock Initiation of a Cylindrical Charge of Homogeneous Nitromethane

F.X. Jetté, A.C. Yoshinaka, M. Romano, A.J. Higgins, J.H.S. Lee, F. Zhang

Shock initiation in a condensed explosive will occur if the incident shock pressure is high enough and if this pressure is sustained a long enough time. The usual approach for investigating the relationship between these two involves a one-dimensional planar incident shock. The only decay mechanism for this type of shock is by expansions coming from behind the shock. In real situations, the pressure and duration of the

incident shock may also vary because of multidimensional effects. The extent of this variation depends on the charge configuration. The interaction of the incident shock with the outer edges of the charge and the extent of its planarity will greatly affect the effective shock pressure and duration in the test explosive. This issue is addressed in the present investigation. A charge setup based on the gap test was used to generate and transmit a shock wave to a test capsule of homogeneous liquid nitromethane sensitized with 5% of diethylenetriamine. The parameters that were varied are: charge diameter, test capsule material, and shock wave planarity. For each configuration tested, the incident shock pressure was varied and whether a detonation is initiated was determined via various diagnostics. The critical pressure for initiation was thereby obtained. It was found that smaller diameter test charges require a higher shock pressure to initiate since the lateral expansion waves coming from the outer edges of the charge reach the center of the charge earlier. Furthermore, the impedance of the capsule material containing the test explosive does not have a marked influence on the critical initiation pressure.

Abstract #107

Condition for Explosion by Impact of a Planar, Self-sustained Detonation

Pierre Vidal, Boris Khasainov

Following our previous analytical and numerical works on shock-ignition processes, we shall summarize a study on one-dimensional planar modeling of the conditions for generating an explosion in a homogeneous reactive substance solicited by a shock resulting from the impact of a Chapman-Jouguet detonation. The detonation is ignited at the closed end of a donor explosive charge ; the target explosive is adjacent to the donor charge. Our objective is to determine the minimal length of the donor to generate explosion in the target. In the configuration considered in the present work, the impact induces a shock in the target and an expansion that goes up the flow of the donor-detonation products. Our approach is based on a preliminary asymptotic analysis about the interaction point for calculating the initial acceleration of the donor-target material interface as a function of the donor length (Cauchy problem). The induction time of the explosion induced by the detonation impact is then obtained as a function of the donor length by inserting the initial acceleration of the donor-target interface in the expression of the induction time of the explosion induced by the impact of a piston with prescribed initial acceleration, that we previously derived and validated by means of direct numerical simulations. The minimal length of the donor charge is that for which the induction time is infinite. We shall present trends and results for the case of explosives modeled as ideal gases that agree qualitatively with the experimental observations and quantitatively with our numerical simulations.

Chemistry in Flames II

Abstract #66

Ignition of Jet-A Fuel on Silver Oxide Deposits

Jeff D. Colwell, Robert E. Peck

Standard aircraft industry practice in preventing explosions of flammable vapors in the fuel tank ullage has been to eliminate all possible ignition sources. One potential ignition source that has received little attention is due to conductive deposits bridging electrical contacts. We have studied experimentally the ignition of Jet-A fuel on silver oxide coatings grown between two wires. The electrical input (current and voltage) required to cause ignition is shown to vary with the method of coating preparation. A logistical regression analysis of the results describes the probability of ignition as a function of the power supplied by the external circuit.

Abstract #204

Chemical Reactions and Energy Exchange under Thermally Non-Equilibrium Conditions at High Temperatures in N2O-CO System

Andrei Yu. Starikovskii

Investigations of monomolecular decomposition of N2O in the region of uncompleted vibration relaxation were performed. The complete task of reaction mechanism development was subdivided into to separate tasks: model of vibration energy relaxation and exchange and model of chemical reactions under non-Boltzmann conditions with participation of excited reagents. It has been shown, that at high temperatures rate of monomolecular decomposition was determined by vibration relaxation of the mixture; the bottle-neck process of this relaxation is inter-molecular energy exchange between N2O and CO. A good agreement between the experimentally measured characteristic times for the reaction (such as a half-increase of O-atoms concentration time) and the vibration energy relaxation time was obtained.

Abstract #126

Rate Coefficient Measurements of the Reaction H + O2 + M = HO2 + M from 950K to 1200K

M.J. Rabinowitz, S.M. Hwang, J.A. Cooke, K.J. DeWitt

Rate coefficients of the reaction H + O2 + M = HO2 + M were measured behind reflected shock waves in a series of very lean H2 - O2 - Ar mixtures (phi = 0.0125 - 0.025). Hydroxyl radical temporal behavior was monitored using 310 nm light (P1(5) line of the (0,0) band of the OH A2S<-X2P transition) from an intracavity doubled ring dye laser operating in a standard double- beam plus frequency reference mode. Experimental mixtures and conditions were chosen after an extensive sensitivity study. The rate coefficient expression is k/[M] = 7.55 x 1017 T-0.8 cm6 mol- 2 s-1 with uncertainty of 30% in the temperature and density range of 950 - 1200 K and 15 - 51 x 10-6 mol cm-3, respectively. Our results are consistent with the

upper range of published values and extrapolation of our expression agrees well with flow reactor studies performed at room temperature. Details of the experimental results and data analysis along with critical analysis and comparison to previous studies will be presented.

Non-Premixed Turbulent Flames I

Abstract #152

Structures and Extinctions in Hydrogen Non-Premixed Lifted Turbulent Jet Flame

Burtsitsig Bai, Yoshiki Shimoshiba, A.Koichi Hayashi, Satoru Ogawa

Two dimensional direct numerical simulation of H2-air lift-off flame with height jet velocity is performed with full chemical kinetics. Hydrogen non-premixed turbulent jet flame structure is obtained and its quenching process at the lifted position is examined.

Abstract #194

Higher-Order Conditional Moment Closure Modeling of Turbulent Nonpremixed Combustion

Chong M. Cha, Heinz Pitsch

Higher-moment closure in singly-conditional moment closure modeling of turbulent nonpremixed combustion is investigated. A priori feasibility studies are done using direct numerical simulation experiments which exhibit local extinction and reignition events. Results show that with moderate levels of extinction, the conditional probability density function (pdf) of the reduced temperature is unimodal, but skewed, and at least the third-order terms in a series expansion of the nonlinear chemical source term is required to predict the singly-conditional means. With higher levels of extinction, the conditional pdf can be bimodal and third-order closure breaks-down. The bimodal structure of the pdf suggests that a presumed form may be of use in future modeling efforts.

Abstract #157

Large Eddy Simulation of Lifted Turbulent Jet Diffusion Flames

Pascale Domingo, Luc Vervisch

Partial premixing is observed in nonpremixed flames when fuel and oxidizer have mixed without burning. This may result from frozen flow mixing found before ignition or from local quenching. In most devices where a spray of liquid fuel is injected, partially premixed flame propagation is observed, as in a gasoline direct injection engine or also in aircraft engines. Therefore in the modeling of many combustion systems, partially premixed combustion should be accounted for. Lifted turbulent jet flame is a laboratory simplified situation where partially premixed combustion is expected. At the flame base, combustion starts in a mixture composed of fuel and oxidizer that have been partially mixed. Downstream of this turbulent flame base, a turbulent diffusion flame develops. Various

experimental and numerical studies have concluded that triple flamelets and edge-flames are the basic ingredients of the turbulent flame base. The modeling of these lifted flames requires the simultaneous description of the trailing diffusion flame and of locally propagating partially premixed flames defined for a distribution of equivalence ratios. A procedure based on the topology of the species field was recently proposed to distinguish in simulations between premixed and diffusion combustion. Combining this approach with Large Eddy Simulation (LES) for the premixed and non-premixed regimes, a subgrid combustion closure for partially premixed flame is proposed and lifted turbulent methane air flames are simulated. The statistical properties of the flame base are collected in the LES, they compare well with experimental observations in term of flow velocity and reveal some properties of partially premixed turbulent combustion.

Abstract #49

Extended LMSE Mixing Model with Chemical Reaction and Injection of Unmixed Concentrations

M. Gorokhovski, V. Sabel'nikov

A further development of the LMSE micro-mixing model is proposed in order to account for the entire spectrum of time scales in the turbulent flow. These scales are described in the framework of the log-normal stochastic process. The evolution equation for the scalar pdf conditional on the given mixing frequency is derived and numerically solved for the simple case of the statistically homogeneous flow. Then, by integration over all range of the mixing frequency, the unconditional pdf is obtained and compared against DNS data. The computation of mixing with chemical reaction was performed. The model is extended for the case of the forcing mixing by the injection of unmixed burnt and fresh gases. Analysis of the combustion have been done when hot pockets are injected by turbulence in the fresh gas or when partially mixed gases are diluted by the injection of fresh gas.

Pulse Detonation I

Abstract #127

The Influence of Driver Power and Receptor Confinement on Pre-Detonators for Pulse Detonation Engines

S.B. Murray, F. Zhang, K.B. Gerrard

There is currently high interest in pulse detonation engines (PDEs) which employ aviation fuels such as JP-10. However, fuel-air mixtures based on these fuels are difficult to detonate. One popular initiation scheme involves the use of a small pre-detonator or driver tube filled with a sensitive and powerful fuel-oxygen mixture. Detonation of the driver gas is relatively easy and, once initiated, the established wave is capable of transmitting to the less sensitive fuel-air mixture in the main combustion chamber. The present paper describes an experimental study aimed at understanding and optimizing pre-detonator performance. One set of experiments was done to determine how much more effective a fuel-oxygen driver is versus a fuel-air driver in terms of its ability to initiate unconfined fuel-air detonations. The apparatus consisted of a steel tube connected to a large plastic bag. Various driver tube diameters were employed. The driver gas was either a stoichiometric or equimolar fuel-oxygen mixture, while the bag was filled with a fuel-air mixture at various equivalence ratios. A thin diaphragm was used to separate the gases. In a real engine application, the strong shock wave exiting the driver tube can reflect from the side walls of the combustion chamber to further enhance the transmission process. Additional tests were conducted to quantify this effect. For this purpose, the various driver tubes were connected to a larger diameter receptor intended to simulate a PDE combustion chamber. The ratio of receptor-to-driver diameters was varied between approximately 2 and 4. Exceptional performance enhancements were observed under some conditions.

Abstract #232

Fuel/Air Initiator Development for Pulse Detonation Engines

Chris Brophy, J. Sinibaldi, D.W. Netzer, N. Setxon

The practical operation of an air-breathing pulse detonation engine(PDE) relies on the ability to produce a detonation wave rapidly and by reliable means over many combustion cycles. The current method used to initiate a detonation in fuel/air mixtures of air-breathing PDEs is to employ a fuel/oxygen initiator unit. These units rapidly and reliably generate a detonation wave in a mixture which is more sensitive than the fuel/air mixture and therefore more easily detonated. The wave then transitions from the fuel/oxygen mixture into the fuel/air mixture which is less reactive and therefore overdriven by the strong leading shock. As long as geometric considerations are met, the resulting fuel/air detonation wave relaxes to steady-state Chapman-Jouget values for that mixture after a short

distance. Ultimately, it is preferable to eliminate the required oxygen for these systems. Tests have been performed to investigate methods to increase the energy release rate of fuel/air mixtures in order to promote rapid detonation wave development. A 101.4 mm diameter combustion tube which contained a reservoir at one end and was 1.25 meters in overall length was selected to evaluate various porous plate geometries. The geometries were evaluated at initial pressures ranging from 1 to 6 atmospheres and initial temperatures ranging from 285K to 450K. The porous plates included a 1-hole, 7-hole, 12-hole, and 24-hole geometries. An optical-access section existed at the head end and could be relocated to provide images of the initiation process. Venting jets from the combustion reservoir have been investigated to determine their shock generating characteristics. The resulting shock waves from the selected geometries were characterized for the location of inception, velocity, and time required for generation.

Abstract #26

Peculiarities of Deflagration to Detonation Transition in Gases

N.N.Smirnov, V.F.Nikitin

Investigations of deflagration to detonation transition in gases are relative to both explosion safety issues, and pulse detonating devices. For both applications the control of detonation onset is of major importance, though the purposes of the control are just the opposite. In explosion safety issues the main goal is to prevent the DDT, while in pulse detonating devices the advantages of detonation over constant pressure combustion bring to the necessity of promoting the DDT and shortening the pre-detonation length. The paper contains the results of theoretical and experimental investigations of control of the DDT processes in hydrocarbon - air gaseous mixtures relative to propulsion applications. The influence of geometrical characteristics of the ignition chambers and flow turbulization on the onset of detonation and the influence of temperature and fuel concentration in the unburned mixture are discussed. Theoretical and experimental results show that self-ignition in one or in a number of hot spots ahead of the accelerating flame followed by the onset of either detonation or deflagration waves brings to a multiplicity of the transition scenarios.

One or two chambers of a wider cross-section incorporated into the ignition section of the detonation tube could bring to an essential decrease of pre-detonation length and time thus promoting the DDT process. The further increase of the number of the chambers up to more than two does not bring to any essential variations of the pre-detonation length in the tube but increases the total length of the device and the pre-detonation time. The use of a multi-chamber structure instead of two chambers followed by a narrow detonation tube brings to establishing of a high speed combustion regime or quasi-detonation regime characterized by velocity much lower than that for the C-J detonation. Thus one or two chambers could be

considered as an optimal configuration to promote the onset of detonation.

Abstract #209

A Study of Detonation Transmission for Facilitating Detonation Initiation in Pulse Detonation Engines

Chiping Li, K. Kailasanath

The pulse detonation engine (PDE) is a propulsion concept based on using the high pressure generated by repetitive detonation waves. In the PDE operation, detonation waves are initiated repeatedly in the PDE tube and a fresh combustible mixture is introduced into the tube accordingly to provide fuel for the detonation. However, there are significant difficulties in initiating and sustaining a detonation in a PDE tube of practical sizes. One possible approach to overcome the initiation difficulty is to use a smaller tube (pre-detonator/initiator) in which detonation waves can be initiated relatively easily and, then, use this detonation to initiate detonation in the main PDE tube. Another approach is to initiate detonation in a more energetic mixture and, then, let this detonation travel into the less detonable, main mixture. In both approaches, the key issue is survivability of the detonation after the transition. A computational study of these approaches as well as others are reported in this paper. The results of the computational study are also compared to experimental observations, where available.

Laminar Flames I

Abstract #202

Laminar Flame - Wall Interaction Study: Stretch Effect Analysis

F. Foucher, S. Burnel, C. Mounaïm-Rouselle, M. Boukhalfa, B. Renou, M. Trinité

In many industrial processes, the combustion is realized in closed chamber. Internal combustion engines have this specification which is involved an important energetic loss by heat transfer. Then, many studies were focused to measure the influence of the flame-wall interaction on the wall heat transfer and on pollutants formation. However, if many results concerning the quenching distance, the heat transfer intensity and the evolution of pollutants formation are available, few authors were studied the effect of the combustion chamber boundaries on the flame propagation speed, flame stretch or the variation of the consumption speed. Recently, Poinsot and al show by Direct Numerical Simulation that walls can affected the development of a turbulent, or laminar, flame even if the distance between the flame front and the wall is important. Then, the aim of this work is to study experimentally the effect of a wall on the development of a premixed laminar methane — air flame in the case where fresh gases are trapped between the wall and the flame front. To separate all phenomena encountered during the engine combustion process, an atmospheric pressure vessel has been developed. The

particularity of this experimental setup is that we can generate different types of flame development (spherical, flatted, wrinkled...), function of the ignition device location. High speed Particle Imaging Velocimetry technique was applied to study the temporal evolution of different parameters. Here we present the temporal evolution of fresh gases velocity, flame displacement speed and stretch of the flame front as function of the local distance between the flame front and the wall in the case of the spherical configuration.

Abstract #200

Effects of Strain on Transient Ignition Characteristics of Hydrogen-Air Mixtures Impinging on a Platinum Plate

Yei-Chin Chao, Hung-Wei Hsu

The characteristics of the transient ignition process of the hydrogen-air mixture in platinum stagnation flow with wide range of strain-rate variation are investigated experimentally and numerically. Surface and near boundary gas-phase temperatures are measured by thermocouples placed in rear and front of the foil. Strain rate is varied by varying the separation distance and the nozzle exit velocity. The computation is accomplished with the SPIN code together with the Chemkin and Surface Chemkin software for gas-phase and heterogeneous chemical kinetics. The results show that the gas-phase temperature rise in the ignition transient follows two or three distinct steps. The gas phase temperature reduces with increasing strain rate, and in the low strain rate conditions, gas phase temperature is higher than the surface temperature and vice versus for high strain rate cases. The results demonstrate that the strain rate effects on the reaction can be divided into gas-phase dominated and surface dominated regions. In the low strain-rate region, gas phase reaction dominated the ignition process and the surface temperature is contributed by the gas phase reaction. In the higher strain rate region, the temperature-increasing rate of gas phase is slightly higher than surface yet the surface temperature is higher than the gas phase. Higher strain rate of the flow stretches the gas phase reaction layer thinner and pushes the layer closer to the surface that reduces the gas phase temperature and enhances the surface reaction due to prohibited gas phase reaction and enhanced species diffusion to the surface.

Abstract #114

Extraction of Basic Flame Properties from Laminar Flame Speed Calculations

A.I. Gavrikov, A.V. Bezmelnitsyn, A.L. Leliakin, S.B. Dorofeev

An extraction of basic flame properties from the data on laminar burning velocity calculations based on detailed chemical kinetic model is studied. An approach is based on the well-known Zeldovich model for the laminar flame with one-step overall chemical reaction and analysis of stretch effects on laminar premixed flames. The problem is studied for practically

important case of hydrogen-air-steam mixtures. A computer code for laminar burning velocity simulation able to calculate these mixtures, including cases close to the limits of propagation, in the plane and spherical geometry is developed. The results of computer calculations were verified with experimental data obtained for normal and elevated temperature and pressure for hydrogen-air-steam mixtures. Special attention is attracted to extract global flame properties, such as effective activation energy, reaction orders, and flame thickness. It was found that effective activation energy is very sensitive to simplifications used to extract this parameter from laminar flame speed variations. The flame response to weak stretch rate variation was also analyzed. The extracted Lewis numbers and Markstein lengths, representing the sensitivity of the flame response to stretch rate were calculated.

Abstract #90

Properties of Propane Flames

Jozef Jarosinski, Jerzy Podfilipski, Yikang Pu

This paper describes an experimental study of the effect of various initial and boundary conditions on propane/air limit flames. Reliable data related to flammability limits and quenching distance concentrations for propane flames are not available in literature. In the present study the flammability limits for upward and downward propagating flames were determined, in a standard flammability tube, and flame quenching in narrow channels was observed and measured. Documentary evidence of the extinction mechanism of downward propagating lean-limit flame was comprehensively supplied. It was also found that the difference between flammability limits, in rich propane/air mixtures, for upward and downward propagating flames, is extremely large. Flammability limits appeared to be f = 1.60 for downward and f = 2.42 for upward propagating flames. Flame behavior between these limits was examined in detail. Propagating upward fuel-rich flames changed their structure depending on mixture concentration: from blue color flames, near the limit concentration for downward propagation, to several-color flames, near flammability limit for upward propagation. Increased content of fuel in the mixture over the limit concentration for downward propagating flame generates increasing quantity of soot. Flame velocities and a visible flame width as a part of the quenching distance at the quenching conditions were measured. It was found that both these quantities are extremely low for mixtures with f>1.75. It was confirmed for propane flames that they can propagate in a channel when the distance between the channel walls is at least twice the flame thickness.

Non-Premixed Turbulent Flames II

Abstract #119

Turbulent Reactive Flow Simulation with Presumed Beta-PDF Combustion Model

A.Kotchourko, B. Burgeth, S.B. Dorofeev, W. Breitung

Presented work has a goal to introduce new numerical technique for mean reaction rate evaluation and to study numerically combustion of lean hydrogen-air mixtures using 'presumed' beta-PDF model. Semi-analytical method for approximate evaluation of integrals of functions with singular behavior at the end of interval was proposed. The method allows to vary parameters of chemical kinetics including activation energy, reaction rate constant and order of reaction remaining with the same set of method's coefficients due to semi-analytical character of algorithm. Proposed technique can be regarded as a highly efficient and very accurate alternative to table look-up and fully numerical evaluation of integrals involving beta-PDF. Approximation of global reaction rate for lean-to-stoichiometric hydrogen-air mixtures ((10-30 % vol.) based on regression of experimental data of laminar flame speeds was proposed. Results of simulations of turbulent reacting flows in obstructed tube geometries and its comparison with experimental data are presented. The simulations were performed for different flame propagation regimes including fast accelerating flames and slow turbulent combustion (<100 m/s). Flamelet and thickened flame regimes were identified in simulations. Detailed results of PDF evolution study during flame acceleration are presented. Comparison of Eddy-Break-Up 'presumed' bets-PDF models was made and validity domains of both models in terms of mixture and environment parameters are determined.

Abstract #45

Modelling of Premixed Turbulent Combustion with Variable Equivalence Ratio using a New << partial pdfs >> Approach

Arnaud Mura, Francois Xavier Demoulin, Roland Borghi

The present study is a new step towards the modelling of complex situations such as turbulent combustion with premixed but non necessarily well homogeneous reactants, herein an original approach to tackle the problem of prediction of the pdf of reactive species is proposed. Practically, turbulent combustion calculations are performed by numerical integration of modelled equations. In usual approach of turbulence, the whole contribution of fluctuations is modelled, whereas in Large Eddy Simulation methods, only effects of fluctuations occuring at scales smaller than resolved have to be estimated. Generally, chemistry is relatively fast so that combustion takes place at scales smaller than resolved, thus the modelling problem of interaction between turbulence and reaction remains. In the paper, a new approach called Partial Pdf Method is proposed and tested ; it can be viewed as an

extension of classical and widely used method of presumed pdf and allows to deal with more complicated forms of pdf than previously done and without having the numerical costs of calculated pdf approach. It is used within the conventional moment approach of turbulence but can also be of interest for LES methodology. In this new method, equations describing the evolution of portions of the pdf are deduced from the modelled balance equation of the whole pdf. Then, balance equations for the weight of each portion, its position and thickness in the sample space are derived and the entire pdf is simply recontructed by a weighted average of partial pdfs. Finally, the method is used to simulate an highly stretched turbulent premixed flame.

Abstract #195

Modeling of Extinction and Re-ignition in Non-premixed Turbulent Combustion

Heinz Pitsch, Chong Cha, Sergei Fedotov

Extinction and re-ignition in non-premixed turbulent combustion is investigated. A flamelet formulation accounting for transport within mixture fraction iso-surfaces is developed. It is assumed that this transport is only due to changes of the local scalar dissipation rate. Space coordinates of the governing equations can then be replaced by the mixture fraction and the scalar dissipation rate. Thereby a new transport term appears in the flamelet equations. The dissipation rate of the scalar dissipation rate appearing as diffusion coefficient of this term is a new parameter of the problem. The resulting equations are simplified and stochastic differential equations for the scalar dissipation rate and the new parameter are formulated. The system of equations is solved using a Monte Carlo method. The results show that the newly appearing transport term acts by increasing the scalar dissipation rate at the lower turning point of the S-shaped curve. The computed joint pdfs of temperature and scalar dissipation rate show similar shapes as observed from DNS data.

Abstract #176

Modelling Of Turbulent Jet Flames

T.J. Craft, Y. Zhang, W.T. Chan

This paper is concerned with the computational modelling of turbulent diffusion flames. The study places particular emphasis on the testing of turbulence models, as many of these have in recent years been widely tested in non-reacting flows, and their strengths and weaknesses in such flows have become reasonably well understood. The performance of both linear and non-linear gradient transport models and second-moment closure (SMC) approaches are investigated. The study highlights the modelling of the stresses and scalar fluxes. It is demonstrated that a turbulence model which resolves the anisotropy of the turbulence could improve the prediction of the spread of the jet flames and flow properties at the outer edge of the flames.

Pulse Detonation II

Abstract #108

Detonation Propagation in Variable Cross Section Channels

Toshi Fujiwara, Ayumi Takasu, Takeshi Miyasaka

Since several years ago, there have occurred the trends to utilize detonation's high-power and high density energy in positive directions like Pulsed Detonation Engine(PDE), where the key issue is whether a true CJ detonation propagates from beginning to end in realistic channels. Therefore, investigations of detonation propagation in variable cross section channels become important in detonation studies. In the past, we developed a 2-dimensional code in constant cross section channels taking into account the transport processes by using simple constant-mesh fine grids. By calculating a 2-dimensional detonation propagation in an oxyhydrogen mixture, we successfully obtained the effect of transport properties to the cell size. In this paper, in order to investigate the fundamental mechanism of detonation propagation in variable cross section channels, the code is extended to allow variable cross section by introducing general coordinate-system. For a purpose of analyzing the propagation process in diverging channels, a fan-shaped channel configurations are employed. The analyses are performed for 3 different inclinations of the channel wall, 0, 3, 5 deg.. As a result, the effects of expansion to the cell size and propagation velocity of shock wave front are obtained. For a larger wall inclination the cell size becomes larger and the propagation velocity decreases slightly.

Abstract #102

Pulse Detonation Engine on Gasoline - Air Mixture

D.I. Baklanov, L.G. Gvozdeva, N.B. Scherbak

The detonation combustion is closer to the process at constant volume and consequently is perspective for designing of pulse rocket engines. Most perspective for PDE is the usage of liquid fuels, therefore in the present paper we will describe DCC operation on the mixture of gasoline with air. DCC consist of a forchamber (with the diameter of 22 mm) and a main chamber (with the diameter of 83 mm), with the diverging cone with a vertex angle equal 16 degrees between the chambers. At the operation in mode of overdriven detonation and MSD mode the convergent cone was added at the exit of the main chamber. Diameter of the outlet varied from 10 up to 30 mm depending on a demanded degree of overcompression of detonation. In the forchamber the ignition from the electric spark in the mixing of fuel and oxidizer occurs and transition to detonation forms. As liquid fuel the gasoline was utillized, which was heated before delivery in DCC up to 70°C. The oxidizer agent was air. The cooling system of DCC walls was applied. DCC worked stable on frequencies of 1-20 Hz during several hours. The DCC was of a valveless type. The main part ensuring a frequency mode were so-called gasdynamics valves, the function of which was

fulfilled by the mains of fuel and oxidizer agents. With their help an overlapping occurred with given frequency of the mains of the fuel and oxidizer agents and unchecked ignition was prevented of fresh portions of a combustion-mixture by combustion products of the previous cycle.

Abstract #73

MEMS-Based Pulse Detonation Engines for Small-Scale Propulsion Applications

Edward Furlong, Ivett A. Leyva, Simon Sanderson

A small-thrust, flight-weight, pulse detonation engine (PDE) is being developed by the General Electric Company as part of a small-scale propulsion systems program. This engine incorporates mesoscopic- and micro-electro-mechanical systems (MEMS) to allow for integrated, large volume manufacturing at reduced cost. The engine development is a joint effort led by GE with Caltech and Stanford University aiding in the engine design, and Arizona State University and University of Cincinnati assisting with the MEMS design. Key uncertainties of the engine design are the minimum combustor size for the desired fuel (JP 8), and the detonation initiation process. In phase I of this program, a series of tasks were undertaken to determine the viability of the PDE concept for small scale propulsive devices and were successfully completed. Numerical models were used to better understand the importance of geometric features, and showed that optimal performance occurred when the ratio of the effective areas of the inlet valve/turbulence enhancing system to the nozzle throat was near unity. Experiments demonstrated detonative performance with liquid fuels (Butane and JP-8) in a flowing system with the assistance of a conical initiator with a 70 mJ spark and a stoichiometric C2H4-O2 mixture. The engine was tested at equivalent free-stream Mach numbers greater than 2.5 at sea level. Pressure transducers were used to capture the time traces during detonations. Phase II of this program, currently underway, focuses on the optimization of the initiation strategy and engine design for liquid fuel systems. The new designs will be built using free-form manufacturing techniques.

Abstract #155

Effect of Transient Gas Dynamic Processes on Impulse of Pulse Detonation Engines

V. Tanguay, C.B. Kiyanda, A.J. Higgins, J.H.S. Lee

The present study is an experimental investigation of the effect of different gas dynamic processes on the impulse produced by a single-cycle pulse detonation engine. The impulse was measured by both the ballistic pendulum method and by the integration of the end wall pressure. The different gas dynamic processes investigated were direct initiation and deflagration to detonation transition (DDT), which were achieved by an exploding wire and a weak spark, respectively. The equivalence ratio of the H2/O2 mixture was varied in order to compare direct initiation to various DDT distances. It was found that for

mixtures where DDT occurred before the last quarter of the tube, the impulse produced by a direct initiation was the same as that produced by DDT. In the range of mixtures where DDT occurred later in the tube (or not at all), but where direct initiation was still possible, greater impulse was produced by direct initiation than DDT. For the case of incomplete DDT, it is believed that the leading shock is decoupled from the reaction zone, ruptures the diaphragm and causes the venting of unburned reactants, which results in a lower impulse. For mixtures insensitive enough that direct initiation was no longer possible, both initiation methods resulted in the same impulse. When the initiation energy is less than the critical energy for direct initiation, the actual amount of energy has little apparent effect on DDT or impulse. Overall, the impulse was found to be independent of the differences in the gas dynamic processes of DDT and direct initiation.

Abstract #182

On the Exit Boundary Condition for One-dimensional Calculations of Pulsed Detonation Engine Performance

Jack Wilson, Daniel E. Paxson

In one-dimensional calculations of pulsed detonation engine (PDE) performance, the exit boundary condition is frequently taken to be a constant static pressure. In reality, for an isolated detonation tube, after the detonation wave arrives at the exit plane, there will be a region of high pressure, which returns to ambient pressure as an almost spherical shock wave expands away from the exit, and weakens. Initially, the flow from the tube is supersonic, and unaffected by external pressure, but later becomes subsonic. Previous authors have accounted for this situation either by assuming the subsonic pressure decay to be a relaxation phenomenon, or by running a two-dimensional calculation first, and using the resulting external pressure temporal distribution as the boundary condition for one-dimensional calculations. These calculations show that the increased pressure does affect the PDE performance. In the present work, a simple model of the exit process is described. The planar shock wave emerging from the tube is assumed to transform into a spherical shock wave. The strength of the spherical shock wave is determined by comparison with experimental results. Its subsequent propagation, and resulting pressure at the tube exit, is given by a numerical blast wave calculation. The model agrees reasonably well with other, limited, results.

Finally, the model was used as the exit boundary condition for a one-dimensional calculation of PDE performance to obtain the thrust wall pressure for a hydrogen-air detonation in tubes of length to diameter ratio (L/D) of 4, and 10, as well as for the original, constant pressure boundary condition. The modified boundary condition had no performance impact for values of $L/D > 10$, and moderate impact for $L/D = 4$.

Laminar Flames II

Abstract #101

Investigation Singing into Conditions Enabling the Excitation of the Kinetic Flame

Vladimir V. Afanasyev, Stanislav V. Ilyin, Nikolai I. Kidin, Nikolai A. Tarasov

Here the object is to describe the present authors, experimental investigations into the contributions of a variety of mechanisms to the development of combustion instabilities in the case of the singing flame. As is evident from the experimental findings, concentration-related excitation and silence ranges could be observed as the propane-air ratio was changed.The occurrence of the concentration-related excitation and silence ranges as a function of Strouhal number. It was found that sound emission will occur at higher frequencies when the oxygen content is increased. The effect of the fuel mixture duct length on the conditions of the excitation of the kinetic singing flame was investigated.

Abstract #70

Buoyancy Effect on Stable and Oscillating Flames in Coflow Jets for Highly Diluted Propane

Junhong Kim, Moo Kyung Shin, Suk Ho Chung

When large size nozzle with low jet velocity is used, the buoyancy effect arises from the density difference among propane, air, and burnt gas. Flame characteristics in such buoyant jets have been investigated numerically to elucidate the effect of buoyancy on lifted flames. It has been demonstrated that the cold jet has circular cone shape since upwardly injected propane jet decelerates and forms stagnation region. In contrast to the cold flow, the reacting flow with a lifted flame has no stagnation region by the buoyancy force induced from the burnt gas. To further illustrate the buoyancy effect on lifted flames, the reacting flow with buoyancy is compared with non-buoyant reacting flow. Non-buoyant flame is stabilized at much lower height than the buoyant flame. At a certain range of fuel jet velocities and fuel dilutions, an oscillating flame is demonstrated numerically showing that the height of flame base and tip vary during one cycle of oscillation. Under the same condition, non-buoyant flame exhibits only steady lifted flames. This confirms the buoyancy effect on the mechanism of lifted flame oscillation.

Abstract #35

Non-Adiabatic Strained Premixed Flames — the Effect of Sudden Transient Cooling by a Pressure Drop

Andy C. McIntosh, John Brindley, Xin-She Yang

Strained premixed flames radiation heat loss define intrinsic flammability limits. The typical response of flame-location or flame-temperature versus strain rate is an isola with a radiation-defined quenching limit at small strain rates, and a stretch-defined quenching limit at large strain rates. When sharp

pressure drops are now put through strained flames near the quenching limit, it is found that not only does the critical value of pressure drop now also depend on the strain rate for these flames, but that the character of the extinction curve is substantially altered as well. This paper extends the earlier work on strain premixed flame to study the effect of sharp pressure changes on quenching limits in the full unsteady state using a thin flat flame approximation together with a prescribed flow field. The flow is regarded as essentially incompressible and uniformly strained. For a given pressure and mass fraction, the increase of heat loss usually destabilises the flame and the normal quenching limits descrease as well. For a given heat loss, the sharp pressure drops make the quenching isola shrink with the normal limit decreasing and the weak limit increasing. When thes two limits meet, no flame can survive the given pressure drop.

Abstract #9

A Singular-Perturbation Analysis of the Burning-Rate Eigenvalue for a Two-Temperature Model of Deflagrations in Confined Porous Energetic Materials

Stephen B. Margolis, Melvin R. Baer

Deflagrations in porous energetic materials are characterized by regions of two-phase flow, where, for sufficiently large flow velocities, temperature-nonequilibration effects can significantly affect the overall burning rate. In the present work, we analyze a two-temperature model of deflagrations in confined porous propellants that exhibit a bubbling melt layer at their surfaces. For appropriately scaled rates of interphase heat transfer, the problem reduces to a nontrivial eigenvalue calculation in the thin reaction region where final conversion of the liquid to gaseous products occurs. For realistically small values of the gas-to-liquid thermal-conductivity ratio, solutions in the reaction zone take on a singular-perturbation character that can be exploited to derive an asymptotic expansion of the burning-rate eigenvalue. The resulting problem requires a rather sophisticated application of techniques in matched asymptotic expansions stemming from the appearance of an infinite number of logarithmic terms in the asymptotic development that must be summed to arrive at the desired level of approximation. The physical effects of temperature nonequilibrium, which decreases the rate of heat transfer from the reacting liquid phase to the gas-phase products and thus allows a greater amount of thermal energy to remain in the reacting phase, are to increase the burning rate relative to the single-temperature limit and to sharpen the transition from "conductive" to "convective" burning.

Non-Premixed Turbulent Flames III

Abstract #44

Heat Release Effects in Lifted Laminar Jet Diffusion Flames

Joan Boulanger, Sandip Ghosal, Julien Reveillon, Luc Vervisch

Recent analytical developments on triple-flame lift-off devoted to the derivation of a stabilization diagram for laminar jet flames are used to compare height prediction against experimental results. To study lift-off properties with an approximate analytical solution, the mixing upstream of the flame base was estimated using a cold flow solution, while the speed of the flame front was obtained from recent derivation of triple flame speed including heat release effects. The comparison between the approximate lift-off height solution and the measurements suggests that some of the specific features of laminar flame lift-off are not included in the cold flow mixing analysis. To understand the observed discrepancies between theory and measurement, numerical simulations of lifted laminar jet diffusion flames including heat release effects are performed. We compare the simulated lift-off height and blow-out position with their approximations provided by the analytical solution. As with the measurements, it is observed that flames are stabilized closer to the burner and the blow out condition is found for velocity larger than expected. The analysis of the simulations reveal that heat release effects strongly modifies both the mixture fraction distribution and the velocity fields at the flame base. Accordingly, the stoichiometric location where the flow velocity equals triple flame velocity is shifted upstream from its cold flow position. In consequence, for large values of the jet velocity, stable flames exist in the simulation for downstream streamwise positions where lean mixture, below the stoichiometric point, are expected in the cold flow theory. Some of the lifted flame properties experimentally observed are discussed at the light of the numerical results.

Abstract #170

Experimental Studies on Flame Stabilization and NOx/ Noise Reduction in Lifted Hydrogen-Jet Flames

Yasuo Yamazaki, Michio Haba, Takasi Endo, Noyuki Himi, A.Koichi Hayashi, Robert K.Cheng

Many combustion systems that use hydrogen as the fuel are assumed to be the most environment-friendly type of combustion. In this research, turbulent diffusion hydrogen-air flame is studied. The whole image and the feature of high-speed hydrogen jet flames are studied using a Schlieren laser systems, a microphone and a NOx detector. Depending on the hydrogen velocity the flame has four modes of combustion: (a) a laminar flame, (b) a turbulent flame with laminar part just behind the nozzle, (c) a low-lifted turbulent flame, and (d) a high-lifted turbulent flame. It has been found that for high velocities the

flame is very oscillatory that leads to very poor flame stability. In the range from the laminar flame to a low-lifted flame the stabilization is much better. The increase of hydrogen velocity also leads to the increase of noise. The noise already exceeds 100dB even for laminar flames but becomes unbearable for high-speed flows. The only one advantage of increased fuel velocity is reduced production of NOx. Based on this comparison it can be found that a low lifted flame is the best-balanced flame in results.

Abstract #74

Raman Measurements of the Stabilization Process of a Lifted Flame Tuned by Acoustic Excitation

Yei-Chin Chao, Chih-Yung Wu, Tony Yuan, Tsarng-Sheng Cheng

Acoustically tuned liftoff flame with good repetition of the flame stabilization process is used for detailed measurements using the line Raman spectroscopy and laser induced fluorescence techniques, which are usually single shot with low repetition, to delineate the stabilization process and to verify the various theories and findings concerning the stabilization mechanism.The flame base is found to locate in lean mixtures for all the phase angles. Combustion products are found upstream of the flame base. This result supports Broadwell et al.'s large scale reentrainment model. The current flame Raman results of mixture fraction and scalar dissipation rate can further substantiate Everest et al.'s cold flow results and Ashurst and William's simulation. The stabilization process of the flame propagation and recession of a lifted flame in an oscillation cycle is described by the evolution of the upstream large scale vortex, the induced strain and dissipation rate on the flammable layer and the flame base.

Abstract #144

Characterization of Non-premixed Hydrogen-oxygen Flame Heights by Chemical Luminescence Imaging and LDV Techniques

J-L. Beduneau, D. Honore, M.A. Boukhalfa

Abstract Characterization of high speed and temperature hydrogen-oxygen flame is an important challenge for optimizing rocket engine injectors and combustion chamber configuration. In this way, the flame height is an important characteristic scale for non-premixed flames. In this study, a non-premixed turbulent hydrogen-oxygen flame is stabilized on a coaxial rocket engine injector type. Flame lengths are determined from mean and rms axial velocity evolution and the axial location of the maximum OH spontaneous emission obtained respectively by LDV and OH chemiluminescence. The obtained results are compared together and also with calculation developed by Driscoll & al [1] on subsonic and supersonic hydrogen-air flame. A good agreement between these experimental results and the expected values is found. The flame lengths increase as the normalized fuel mass flux decrease,

where the normalized fuel mass flux is defined by the ratio of the hydrogen mass flux on the oxygen mass flux. Flame lengths reach a limit value for important normalized fuel mass flux.

Abstract #47

Identification of the Transfer Function in a Model Gas Turbine Combustor: Application to Active Control of Combustion Instabilities

Daniel Bernier, Sebastien Ducruix, Francois Lacas, Sebastien Candel, N. Robart, T. Poinsot

Due to their good performances in term of low pollutant formation, the lean premixed prevaporized combustion chamber design has received a special interest in the field of gas turbines. This work reports an experimental study of a laboratory scale lean premixed prevaporized swirl stabilized combustor operated with preheated air and liquid heptane as fuel. In certain operating conditions, it exhibits strong combustion instabilities ay frequencies near 400Hz. An actuator was designed and implemented in the LPP injector so that the transfer function of the burner and actuation system could be measured. Two different techniques were used for the identification of the system: either direct identification between command and pressure signals, either minimization of a Finite Impulse Response filter. The two techniques show a good agreement. This identification could then be successfully applied to active control of combustion instabilities. The mean pressure oscillations amplitude could be reduced from 650Pa to 400Pa.

Pulse Detonation III

Abstract #60

Use of Thermochemical Conversion in Pulse Detonation Engine

D.I. Baklanov, V.V. Golub, O.G. Divakov, A.V. Eremin

To create pulse detonation engine thermochemical conversion is proposed. There is shown that thermochemical conversion prepares new modified fuel and as result the possibility to use fuel-air mixtures in pulse detonation engine appears. Moreover, the thermochemical conversion is shown to provide the temperature of the wall of combustion chamber below the spontaneous combustion value. The analysis of heat capacity and cooling resource of hydrocarbon fuels and ammonia is done.

Abstract #106

Combustible Mixture Injection and Ignition in Downstream of 2-D Detonation

Toshi Fujiwara, Soshi Kawai, Takeshi Miyasaka

A 2-dimensional analysis of pulsed detonation engines (PDE) cycles containing Ar-diluted stoichiometric oxyhydrogen mixture is performed. For the purpose of achieving high-cycle PDE, we specially pay attention to its injection and ignition in the 2nd cycle, where the burnt gas generated in the 1st cycle

remains. In this analysis, a 2nd accurate MacCormac-TVD scheme is used for Navier-Stokes equations and a two-step chemical reaction model is introduced. A simple type PDE of straight shape is considered, which has the closed upstream end having Ar-diluted stoichiometric oxyhydrogen mixture injection port and igniter while the downstream end is open for the exhaust of burnt gas. In this model, a calculation of 1st cycle starts after an Ar-diluted stoichiometric oxyhydrogen mixture is filled up in the channel of 3cm width and 38cm length at the initial pressure 5atm and temperature 298.15K. The ignition is artificially performed by assuming the CJ detonation obtained from 1-dimensional analysis. As s result, the detonation propagation is achieved in the 1st cycle. Immediately after the shock wave front reaches the downstream end, a fresh combustible mixture of 3.0atm initial pressure and 298.15K temperature is injected from the injection port. The result at 2.82x10-3 sec after injection start shows clearly that the result that the injected fresh combustible mixture is expanded in the channel and diffuses into the burnt gas.

Validation of Reduction Procedures

Abstract #175

Validation of Selection Parameters for Steady State Species for Automatic Reduction of Chemical Mechanisms

Terese Løvås, Daniel Nilsson, Fabian Mauss

The combination of chemical kinetic models with Computational Fluid Dynamics calculations used for prediction of gas flow in combustion chambers provides an efficient tool in terms of time and costs for the investigation of the overall combustion processes. In order to define steady state species for the development of automatically reduced chemical mechanisms a reliable and simple selection criteria for steady state species needs to be used. Such a selection criteria can be the chemical lifetime of a species based on the assumption that species with shorter lifetimes than physical processes involved can be set to steady state. Another selection criteria can be a combination of the lifetime with a species sensitivity in order to capture species with overall little importance because of small lifetime and/or a low sensitivity on the desired result thus meaning the species can be computed by approximate means. In this work we have investigated the validity of these selection parameters and their use for selection of steady state species. We find that the error in computation of the species concentration is linearly increasing with lifetime and conclude therefor that a simple first order lifetime measure is a valid and usefuel selection parameter.

Abstract #18

Validation of a New Chemistry Reduction Method for Partially-Premixed Laminar Methane/Air Flames

Olivier Gicquel , Dominique Thevenin , Nasser Darabiha

Partially-premixed laminar flames are of great importance for

domestic burner manufacturers. They represent the most attractive solution to cope with the latest pollutant emission regulations. In order to correctly describe such a laminar flame, it is very important to accurately represent all the phenomena (convection, diffusion and reaction) throughout the flame front. That is why we need to use detailed chemistry mechanisms instead of single-step chemistry. Unfortunately detailed mechanisms include more than fifty species in the case of methane/air flames. A solution to overcome this problem is to use reduced mechanisms. There are different ways to generate these mechanisms. The classical technique is based on physical assumptions (steady state, partial equilibrium...). This technique gives good results but requires an impressive knowledge in chemistry and is very costly in terms of human time. As industrials can not afford such a solution, researchers have more recently developed fully automatic techniques to provide reduced mechanisms. Maas proposed a reduction technique, called ILDM, based on the study of the chemical local time scales. More recently, the Flame Prolongation of ILDM (FPI) method, a new improvement, was proposed. Its main advantage is that the description of the low-temperature phenomena is based on better physical assumptions. In the present work, this technique is used to compute partially-premixed laminar flames. To validate the FPI technique, three test-cases were simulated in the TOPDEC burner configuration. This burner is an idealised partially-premixed laminar burner which is developed in an European Community project. Simulations were compared to OH and temperature measurements.

Laminar Flames III

Abstract #151

Computational and Experimental Study of Ammonium Perchlorate Counterflow Diffusion Flames

Mitchell D. Smooke, Richard A. Yetter, Timothy P. Parr, Donna M. Hanson-Parr

We investigate the modeling of counterflow diffusion flames in which the products of AP combustion are counterflowed against a methane fuel stream. The two-dimensional problem can be reduced to a one-dimensional boundary value problem along the stagnation point streamline through the introduction of a similarity transformation. By utilizing recent developments in hydrocarbon, chlorine, NOx and AP kinetics, we can formulate a detailed transport, finite rate chemistry system for the temperature, velocity and species mass fractions of the combined flame system. We consider both gas phase and condensed phase chemistry. We compare the results of the model with a series of experimental measurements in which the temperature is measured with radiation-corrected thermocouples and OH rotational population distribution, and several important species are measured with planar laser induced fluorescence and emission spectroscopy.

Abstract #42

Experimental Study of Low Reynolds Number Reacting Flows: Gas-gas Laminar Flat Plate Diffusion Flame in Microgravity

Pierre Cordeiro, Pierre Joulain, José L.Torero

The study of highly exothermic reacting low Reynolds number flows has received nearly no attention in the past. The main reason being that highly exothermic reactions such as those common in combustion processes, result in buoyantly induced flow that generally characterised by Reynolds number greater than 1000. Motivated by fire safety concerns and the advent of long term micro-gravity facilities, a renewed interest in fire propagation at very low Reynolds number has arisen. The complex mixed flow fire scenario observed in normal gravity is reduced to the classical combustion problem of a chemically reacting boundary layer flow over a flat plate, that of an incompressible boundary layer flow with blowing. In this stage the study of the effect of fuel injection and of the flame on the flow structure was emphasized. After showing the existence of different stability regimes and of extinction limits for both cases, we now like to better describe the structure of the reacting flow by still using optical diagnostics. Different visualisation and optical diagnostics were successfully used to characterise the flow field and to properly located the flame. Three different domains have to be considered. Two stable regimes for blue and yellow flames and a transition regime between the two and the non-propagating or extinction zone.

Poster Session II

Abstract #230

Turbulent Combustion of Sprays

H.H. Chiu

The objectives of this article are to present an axiomatic theory of the interfacial exchage of a droplet in turbulent environment and the two-phase flow structure under the effects of modulation of the carrier gas. Specifically, the analysis covers the predicitons of the laws of droplet gasification, the flow structure and combustion characterisitcs under the influence of the modulations of turbulent kinetic energy and the rate of energy dissipation. The theory serves to identify all the sub-mechanisms and the rigorous analytical assessments of the extent of moduation by each sub-mechanism. The law of droplet gasification in turbulent flow environment is derived from the conservation equations of turbulent reacing flow. The effects of molecular and turbulent transport processes, turbulent kinetic energy and dissipation rates are taken into account in the formulation. The results are in good qualitative agreement with experimetal measurements. The structure of the particle ladden jets of steady axisymmetric configuration, i.e., the spatial distributions of velocity, temperature, turbulent kinetic energy, and the rate of dissipation are represented by axiomatic forms in such a manner that all the mechanisms

contributing the flow structures appear explicitly in the exact axiomatic solutions. The theoretical results shed light on the detailed interlinking mechanism among major modulation processes and provide genuine understanding of the structure of turbulent flows. The article concludes with the discussions of the future research that aims to the understanding of basic problems including flamelets, collective interaction, group phenomena, eddy-droplet interaction in dense spray structures.

Abstract #223

Modeling and Control of Mixing in a Transverse Jet

Youssef M. Marzouk, Ahmed F. Ghoniem

The mixing properties of the transverse jet are important in combustion systems and a variety of other engineering applications. Enhancement of the mixing rate between jet and crossflow can lead to significant improvements in system design and performance. Our objective is to develop control strategies for the transverse jet that enable the enhancement or reduction of the mixing rate between the jet fluid and the crossflow. Prospects for control are supported by the presence of large-scale coherent vortical structures in the flow field. We develop a computational model which can capture the evolution of these structures and their response to upstream actuation. Computation serves an investigative tool for the fundamental physics of the flow field, and acts as a testbed for demonstrating the effectiveness of proposed actuation mechanisms and control design. A three-dimensional vortex filament method is used to simulate the flow field of an incompressible transverse jet at high Reynolds number. Filaments are used to transport the azimuthal and axial vorticity injected into the flow field at each timestep; arbitrary modes of actuation are allowed. Results show that the computational model captures the essential vortical features of the transverse jet: rollup of the jet shear layer in the near field, and bending and tilting of vortex rings to form a counter-rotating vortex pair approximately aligned with the jet trajectory. Ongoing work will elucidate the role of these structures in mixing and their response to actuation.

Abstract #216

Model Studies of Fuel Injection

Wieslaw Glinka , Zbigniew Gut , Eugeniusz Budny , Janusz Przastek

The results of fuel atomization studies in open space and in constant volume chamber are presented. High pressure fuel injector made by Mitsubishi was used in the studies. Photographic method developed at KAIST Korean Institute was applied in the study of atomized fuel structure in open space. It consists in the use of the system which contains: light source, CCD camera and PC computer with the frame grabber software and control system. Series of photographs were made for fixed focal plane with respect to injector axis which were then used by PC software to determine Sauter mean diameter of the droplets. Fuel injection structure in the cylindrical constant volume

chamber was studied by optical method. The chamber was equipped with two windows enabling visualization of the process. Typical Schlieren optical system was used, composed of light emitting diode and high speed drum camera. Photographs were transmitted to computer for further processing. Fuel injection studies were conducted in the chamber for two cases: without initial air swirl in the chamber and with the initial swirl. The studies were conducted for different times of injection delay and with the variable duration of injection — in order to form the mixture of given air excess coefficient l. The results of the study in the form of Schlieren photographs of fuel injection to the chamber enable for detailed analysis of: initial shape of the fuel jet, jet variation in time, mixing process and droplet vaporization, fuel interaction with the walls, regions of different droplet concentration, etc. The reported studies are the part of larger project embracing also ignition and combustion. The study was supported by the State Committee for Scientific Research under the grant No.PB 088/T12/99/17 (research Project No. 9T12D02317).

Abstract #71

Simulation of Combustion of Supersonic Hydrogen Jets in a Supersonic Air Flow

Sh.A. Ershin, U.K.Zhapbaspayev, A.Kaltayev, T. Fujiwara

The results of numerical simulation of hydrogen combustion in a supersonic air flow are given. The supersonic hydrogen jets (T=254 K, M= 1.8) injected into supersonic air flow(T=1270 K, M=3.63, YO2=0.266, YH2O =0.256, YN2=0.478) at different angles (0, 30). The turbulent mixing and combustion are governed by time averaged and parabolized Navier-Stokes equations using two-parametrical "k-l" turbulent model and detailed kinetic mechanism of hydrogen oxidation. The behavior of supersonic hydrogen combustion are considered and investigated in tasks: 1) a system of flat hydrogen supersonic jets are injected parallel into supersonic flow and at different angles; 2) a system of round or elliptic hydrogen supersonic jets injected into supersonic flow; 3) a system of round or elliptic hydrogen supersonic jets injected into supersonic flow with subsonic zones. The influence of fuel and oxidiant parameters on completeness of hydrogen combustion were estimated.

Abstract #82

Probe Method of Sampling of Combustion Products of Solid Rocket Propellant at Temperatures and Pressures Typical of Combustion Chamber of Rocket Motor

O.P. Korobeinichev, A.G. Tereshenko, P.A. Skovorodko, A.A. Paletsky, E.N.Volkov

New probing technique for determination the composition of combustion products of composite solid rocket propellant (CSRP) at temperatures 2500-3200K and pressures 4-8 MPa typical of rocket motor is described. A two-stage probe device, which enables to freeze the sample passing main shocks inside

the probe, has been designed. The first stage probe with inner opening angle of the cone 90 and pressure inside the probe ~20 torr extracts the samples from the flame, and the second stage ´ from underexpanded free jet formed inside the first stage. For estimation the probe sampling accuracy the gas flow simulation based on numerical solution of Navier-Stokes equations has been performed. By chemical kinetics equations solution it is shown that in the sampling process the concentration of the majority of stable species distorts in the range of 2 - 3%, and for H_2 and O_2 ~ 12%. The simulation of sample flow through the second stage of the probe have shown, that growth of temperature and pressure due to mixing of high-enthalpy hypersonic flow with surrounding gas does not initiate the chemical reactions, which could distort the sample composition. The method allows performing additional operations after sampling, particularly, separation of CO and N2 in the sample composition with further analysis by time-of-flight mass-spectrometer. CO and CO_2 concentrations in combustion products of model CSRP ´ ammonium dinitramide with polycaprolacton at pressure 4 MPa has been determined. The method can be applied for diagnostics of combustion processes in rocket motor, as well as in aircraft engine chamber and internal combustion engine.

Abstract #100

Numerical Simulation of Dust Layer Dispersion Due to Rarefaction Waves

Rudolf Klemens, Pawel Kosinski

Dust-air explosions in industrial facilities lead to severe accidents and casualties. The main tasks of the researchers who deal with those problems are to investigate the phenomena and to find methods of prevention and mitigation. The most popular is the usage of venting systems that reduce the pressure rise and in this way protect the facility against destruction. However, it produces a rarefaction wave propagating back towards the vessel. Such a phenomenon in the presence of dust layers located in the vicinity of the diaphragm may turn out especially dangerous when there has been no serious explosion, but only an instantaneous pressure rise due to some local and small-scale effects. The rarefaction wave may lift the dust from those layers and form a combustible dust-air mixture. In the present research numerical simulation of the phenomenon has been performed. The objective has been to see whether it is theoretically feasible to predict the creation of the combustible mixture caused by the presence of the rarefaction waves. In order to model the phenomenon, two cases have been considered. The first one simulates one-dimensional flow in a duct, which is divided into two parts: the high- and low-pressure sections. The difference of pressure creates a rarefaction wave that propagates into the high-pressure section. A dust deposit is located in the high-pressure part, so the rarefaction wave acts on it, and causes the dust to be lifted. The second case simulates two-dimensional dust lifting in a complex geometry domain, which corresponds to some real facility.

Abstract #160

Modeling of CO Formation in Turbulent Premixed Combustion

Per Nilsson, Xue-Song Bai

In this work the influence of flame stretch on the formation of CO in a lean premixed propane/air turbulent flame is studied. In the flamelet regime, it is shown that flame stretch affects turbulent flames in two ways. One is through the modification of the local laminar flamelet structure. High flame stretch leads to short flow residence time and fast heat and mass transfer rates. The competition between the fast rates of heat and mass transfer and the chemical reaction rates yields an incomplete combustion in the post-flame zone and even local flame extinction. The other effect of the flame stretch is through the modification of flame propagation speed. These two effects are taken into account in the present numerical calculation using a level-set flamelet library approach. Using a detailed chemical kinetic mechanism on a model back-to-back twin-flame configuration for the calculation of the locally strained flamelet structrues, together with additional modeling on the mean flame position, thickness and mean flame strain rate, the experimentally observed high CO emissions in the post-flame zone are successfully simulated.

Abstract #21

Calculation of Deflagrating Flame in a Rectangular Duct with Internal Solid Obstruction

S.S. Ibrahim, S.N.D.H. Patel, G.K. Hargarve

In this paper, results are presented from numerical calculations of turbulent flame propagation in an explosion combustion chamber. Stoichiometric mixture of methane-air was used to study the flame deflagration from a closed end of a rectangular (0.15´0.075m), 1m long open ended duct with a single built-in solid obstacle. The rectangular obstacle is positioned across the duct cross-section at 0.15m from the ignition end, and its dimensions are 0.04´0.075´0.012m resulting in a blockage percentage of 50%. Time dependent semi-implicit calculations were made to solve density weighted (Favre-averaged) conservation equations for mass, momentum, turbulence, reaction progress variable, and energy. A two equation eddy viscosity turbulence model modified for compressibility effects is used to close the conservation equations. Also, recently developed laminar flamelet model has been used to close the mean rate of chemical reaction. It is found that the flame propagates through different regimes of combustion following ignition and as it travels around the obstacle. Calculated values for the flow Reynolds and Damköhler numbers suggested that the combustion within the explosion chamber, above, lie between wrinkled and corrugated flamelet regimes. Comparison between experimental and predicted results of flame shape, flame speed, and pressure show that the characteristic trends are well reproduced. It is concluded that the formulated model described in this paper predicts realistic results for flame deflagration over solid obstacle inside semi-

confined chambers. The accuracy of the model was improved significantly when: 1) The transition from near laminar (early stages following ignition) to highly turbulent stretched flame is controlled through the laminar to turbulent stretch ratio, and 2) The flamelet wrinkling length scale is properly related to the turbulence intensity and length scale.

Abstract #219

Analysis of the Critical Conditions of Ignition of Gas-suspended Solid Fuel with a Heated Surface

Boris S. Seplyarskii, Tatyana P. Ivleva

The present paper reports the results of the theoretical analysis of the process of ignition of gaseous suspensions with a heated body at the pulse energy supply. The process is described by a one-dimensional mathematical model suggesting the difference between the particle and gas temperatures. The study was aimed at determination of such pulse duration equal to as a function of the governing parameters, that at > the gas suspension is ignited, i.e. the combustion wave propagation is initiated, while at < the process of chemical conversion could be stagnated. In accord with the ideas of WTI, = , where is the time of the zero gradient establishment on the suspension-heater interface at . As shown by the results of numeric calculations, = for the kinetic (one-temperature) regime of ignition, while in the diffusion regime ignition could be expected at < . The result is the consequence of the absence of the positive reverse relation between the heat release rate and the particle temperature in the diffusion regime of interaction. The more detailed calculations showed that the minimum ignition time can be achieved at = . The formulas for the ignition delay time and the critical conditions of ignition at < were derived. The study was supported by RFBR (Grant 00-03-32034) and INTAS —ESA (Grant99-00138).

Abstract #58

Gas and Coal Dust Combustion with Staged Air and Pulsation Effect

Lech Szecowka, Henryk Radomiak

Combustion plays a dominant role in energy production and at the same time is a main source of the air pollution. Paper presentation modification of combustion process in order to lower emission of NOx introducing staged air of combustion. In addiction the secondary air stream was disturbed by pressure pulsations. The usage uf the mentioned actions caused 90% CO emission reduction, and with low levels of excess air ration the NOx emission was also about 10 - 20% lower.

Abstract #197

Combustion Mechanism of the Multi-way Impinging-type Burners

Jing-Tang Yang, Han-Chang Cheng, Fu-Ane Chen, Shiung-Fu Chen

The flame structure of multi-way impinging-burners were experimentally investigated and systematically compared with

those of the flat-type design. Three types of the burners, a two-way impinging burner, a three-way impinging burner and a flat-type burner were systematically studied. Instead of the traditional 2-D layout, the steric concept and the impinging flow design built within the dip of the burner were adopted for both the two-way and three-way impinging burners. Main theme of the experiment was on the comparisons among the three burners, especially on the flame configurations, the stable operation ranges, the distributions of velocity and temperature in the flow, the thermal and flow characteristics within the dips of the impinging burners. The fuel was the commercial-grade propane gas and the major controlling parameters were the flow rates of the fuel and the primary air. The experimental results indicated that the new designs effectively reduced the flow velocity around the ignition zone and restructured the flow pattern to be favorable of combustion. It also generated small recirculating bubbles within the dip and significantly preheated the air/fuel mixture. All these factors raised the temperature of the combustion products, enlarged the stably operating range, and improved the combustion instability of the burners. Similarities and differences in reacting flow between the two-way and the three-way impinging burners were also discussed in detail. Quantitative studies on mean flow structure, mean temperature distribution, and flow fluctuations further confirmed the superior combustion mechanism of these impinging-burners.

Abstract #222

Inverse Methods In Interior Ballistics Processes Study

Vladimir Arkhipov, Evgeny A. Zverev, Dmitry A. Zimin

Abstract #229

Radiative Properties of Water Vapor by Optical Study of Hydrogen-air Combustion

Pascale Chelin, Vincent Pina, Philippe Hervé

There is a universally accepted need to monitor and minimize pollutant emissions from combustion processes. To contribute to the development of more competitive combustors by the command of heat exchanges, the determination of temperature and concentration distributions of combustion products is required. Because the intrusive sensing techniques can not be used under severe conditions ($T > 2000$ K and $P > 5$ bar), emission spectroscopy of gas species has been investigated for passive and non-intrusive measurements. The physics governing radiation emission and propagation are directly influenced by gas species, composition and concentrations, hence a high degree of theoretical and experimental analysis of typical gas samples is required for accurate modeling. In our laboratory we have designed an experimental facility to analyze line broadening of high pressure combustion products in a transient phenomenon. This paper is aimed at providing preliminary emission measurements of water vapor produced as a burnt gas from confined combustion of a reactive hydrogen-air mixture for different initial conditions. The experimental spectroscopic

measurements were performed in the 0.8 μm band of H2O using a high resolution grating spectrometer and a CCD detector. These spectra are compared to simulations with the HITEMP compilation. In the measurement spectral range, the line widths are not very sensitive to total pressure. We can obtain detailed information of H2O spectral lines at any pressure that should be very helpful for the retrieval method to determine temperature profiles into combustion processes.

Abstract #67

Turbulent Combustion in Cellular Detonations

A. Efimenko, S. Dorofeev

A role of turbulent combustion as an important mechanism for energy release in real detonations and its relation to cellular detonation instability is discussed. Results of two-dimensional time dependent simulations of detonation processes in reactive gas with a specific energy release model are presented. The model is used that mimics some features of the energy release in turbulent reactive flows. An effective turbulent burning velocity is used in the model with the burning rate dependent on vorticity. No temperature dependence of combustion rate is assumed in the model. It is found that for a certain range of burning rate constants detonations is formed, and instability is developed with cellular structure typical for real detonations. As it is typical for simulations with Arrhenius kinetic models, the characteristic size of the cells is inversely proportional to reaction rate constant. The results shows that cellular detonation instability cannot be considered itself as an indication that autoignition via adiabatic compression is the main mechanism of energy release in detonations. The mechanism similar to turbulent combustion is able to be responsible for cellular detonation instability.

Abstract #5

Theoretical Study of Shock Wave Ignition of Aluminum Particles

Tao Hong

The ignition of Al particles behind shock waves is theoretically studied with three different criteria. The ignition delay times with different Mach number of incident shock waves are obtained and compared with experimental results. In this paper the process of accelerating, rising of temperature and ignition of particle behind the shock waves is analyzed. An ignition criterion of the particle in the flow field behind shock waves is proposed. Theoretical results show that Al particles can be ignited at the temperature much lower than the melting point of Al oxide in the flow field behind shock waves. In this paper it is assumed that an Al particle can be ignited as its temperature reaches the melting point of Al and all of the Al of the particle is melted behind shock waves. The ignition delay times obtained by this criterion are best agreed with the experimental results in some conditions. If a particle is thick covered by oxide, its ignition temperature will be at the melting point of Al oxide.

Abstract #29

On Modeling of Electrochemical Detonation Pulsejet

V.Korobeinikov, V.Markov, I.Semenov, S.Wojcicki

Models of electrochemical pulse jet with combustion, implosion and detonation are studied in the paper. An electrodischarge in the combustion chamber is used to improve efficiency for conversion of thermal energy into mechanical that. This electrodischarge can convert combustion into detonation . The discharge appears in the combustion chamber when the flame front impinges on special electrodes that are attached to energy storage capacitor. A collar(ring-shaped) discharge creates converging shock waves in the combustible mixture, leading to detonation and increasing in the compression ratio. The energy of combustion of one cycle is much higher than the electrical energy of the discharge. Modeling of these processes includes the converging shocks and detonation waves. Numerical simulation of gas flow in the chamber and in connecting intake and exhaust tubes has been implemented. Chemical kinetics, wall friction, heat losses and two-phase combustible mixture burning are taking into account. The calculations are made for several initial conditions, types of combustible mixtures and implosion mode. Output from the model includes impulse, thrust values and engine efficiency. A small-scale experimental devices have been constructed and base data measured. It can be modified and used to create intense spark channels which initiate the implosion in the combustion chamber. The application of implosion schemes to RAM Accelerators is also discussed. Graphs, pictures and diagrams demonstrate the results.

Abstract #57

Influence of Small Additives of Xe on Detonation Threshold of a Mixture of O_2, H_2, and He.

Serguei Koulikov, Georguei Manelis

The influence of a small additive of Xe on a detonation of a mixture of 10%H2+5%O2+85%He was experimentally investigated.It has appeared, that at replacement 0.5%He on 0.5%Xe stable detonation was observed in waves of lower intensity The cause of this is the appearance in front of a wave of stronger translational nonequilibrium accelerating chemical interaction O2 and H2. Calculations were carried out by Monte Carllo method of the unstationary statistical simulation with constant weighting factors.They have shown that such a translational nonequilibrium takes place in conditions of experiments. Probably, the considered experiments are most convincing and vivid example of appearance on macroscopic level of microscopic effect of translational nonequilibrium.

Abstract #25

Initiation of Detonation in Confined Volume by Converging Shock Wave

V.Levin, V.Markov, S.Osinkin, T.Zhuravskaya

The problem of a direct initiation of spherical and cylindrical

detonation in a stoichiometrical hydrogen-air mixture under normal conditions in the space, confined by rigid shell, as result of low pressure domain collapse is under consideration. The investigation of the flow with taking into account the detail mechanism of chemical reactions is done by a finite-difference method based on the Godunov's scheme with a moving difference grid and explicit capture of the leading shock and the contact surface. It is obtained, that under given low pressure in the collapsing domain and its radius being equal or greater the known radius for the case of unconfined space, there exists the minimal critical radius of the shell, starting from which the detonation wave is formed into the flow field under consideration. At that the internal energy of the spherical layer located between the shell and the low pressure domain, a part of which is spent on the detonation initiation, has the minimum that essentially exceeds the critical energy for the case of the detonation initiation in unconfined space with help of the TNT charge. It is detected that under fixed value of low pressure the difference between the critical radius of the shell and the low pressure domain radius approaches to some finite value when the low pressure domain radius is increased. This work has been supported by the Russian Fundamental Studies Foundation under Grant No. 99-01-00323.

Abstract #203

Spark Ignition in the Pre-Heated CH4-Air Mixtures Behind Reflected Shock Waves

Alexaner B. Britan, Gregory Pilch, Eran Sher, A. Yu Starikovskii

Spark ignition of premixed CH4-Air mixture was investigated using shock tube technique and 3D - numerical modeling. Flame propagation was investigated using flame self-emission technique and high-speed laser-schlieren photography. It was shown, that on the initial part of the trajectory the flame velocity greater than on the final one for all cases which was connected with the heat exchange regime modification; variation of the ignition initiation regime practically does not change the flame front propagation regime. Formation of the first cylindrical flame kernel in the experiments may be explained by the temperature field nonuniformity in the vicinity of the spark plug.

Abstract #103

Spontaneous Detonation in the Mixture of Initial Reagents with Hot Detonation Products

V.I. Tarzhanov, I.V. Telichko, V.G. Vildanov, V.I. Sdobnov

RFNC-VNIITF proposed the way and TSD-01M facility for quantitative investigation of basic mechanisms of deflagration to detonation transition (DDT) in unconfined clouds of accidental fuel release. The facility creates the mixture of the initial propane-air composition with hot detonation products (HDP) in part of the main tube. Hot products occur and are injected into the main tube of the facility when the initial

composition is detonated in the small perforated tube. The first series of experiments was carried out to determine critical energy E* of the direct initiation of the initial mixture with HDP and to compare E* with that of the initial reagents (6 vol. % C3H8). E* was obtained to be 19 J/cm2 and 37 J/cm2, accordingly. Mixture with hot detonation products was not force-initiated in the case of spontaneous detonation registration. Spontaneous detonation was observed both in the area with hot detonation products, and at the boundary of this area with initial reagents. With used concentrations and the gradient of HDP concentration the "island" of spontaneous detonation, i.e. the concentration range (3.3 — 5 vol. %) of propane in the initial composition where spontaneous detonation is realized with 1.7-3.1 ms delays, is discovered. In some experiments a not taken place spontaneous detonation, as well the classical DDT with shock wave acceleration were observed.

Pulse Detonation IV

Abstract #20

JP-10 Vapour Detonations at Elevated Pressures and Temperatures

Fan Zhang, Stephen B Murray, K. Gerrard

Potential operating conditions for pulse detonation engines may lie between atmospheric pressure and the stagnation pressure at the maximum flight Mach number. Therefore, it is necessary to know the detonation properties of fuel over a wide range of initial pressures, temperatures and equivalence ratios. The present paper studies the detonation properties of JP-10 vapour-air mixutres at pressures ranging from 103 kPa to 500 kPa and temperatures up to the auto-ignition point for various mixture equivalence ratios. A Schedule 160, heated detonation tube 20 cm in inner diameter was designed for this purpose. Smoke foils were employed to record detonation cell sizes and ion gauges were used for measuring detonation velocities. Preliminary experiments for the stoichiometric mixture show that for initial pressures up to 210 kPa and temperatures from 400 K to 503 K, the detonation cell width is approximately inversely proportional to the initial pressure. The correlation of the cell size with the initial pressure is to be further investigated up to 500 kPa. In the preliminary tests, the influence of the temperature on the cell size was embedded in the error range. To determine the dependence of the detonation cell size on temperature and the optimum fuel-to-air ratio for engine operating conditions, measurements for the detonation cell size are currently being conducted systematically up to the auto-ignition point and also for off-stoichiometric conditions.

Abstract #97

Electric-Discharge Control of Pre-Detonation Processes

Vladimir V. Afanasyev, Stanislav V. Ilyin, Aleksei V. Lapin, Nikolai I. Kidin

A technique for controlling the pre-detonation flame

acceleration in ducts closed at one end by initiating a diffuse electric discharge within the flame zone from a special-purpose power supply is investigated experimentally. It is demonstrated that when a constant-current electric discharge is applied to the flame zone the pre-detonation flame acceleration will be retarded and the pressure increase rate will be reduced. Alternatively, a constant-voltage electric discharge will intensify the flame zone turbulisation processes and reduce the pre-detonation flame acceleration time. It has been established that the frequency characteristics of the power supply feedback chain exert an essential influence on the processes under investigation. When the power supply feedback chain passband is increased, the pre-detonation flame acceleration time will increase in the case of the constant-current discharge and decrease in the case of the constant-voltage discharge.

Swirling and Enclosed Flames

Abstract #53

Extinction Mechanism of Swirling Lean Methane-Air Flames

Kazufumi Yorimori, Makihito Nishioka, Tadao Takeno, K.N.C. Bray

The extinction behavior of the swirling lean methane/air twin flame was studied numerically in terms of the 1-D similarity solution with detailed kinetics. In this numerical study with detailed kinetics the attention was focused on identifying the elementaly reactions which control the extinction, and thus to understand the extinction due to incomplete combustion. Specifically, the behavior of the maximum temperature and the concentration of main intermediate products, such as CO and H2, at the stagnation plane were studied as the extinction condition is approached. The study has revealed the several interesting behavior; the critical stagnation temperature at the extinction remains almost the same for different counterflow injection velocities and the no-rotating counterflow injection velocity. CO and H2 profiles at the extinction remain almost the same as well. Furthermore the main species profiles, such as CH4 and H2O, also remain the same at these extinction conditions. That is, the extinction occurs with the identical flame structure for the different injection velocities. The balance of three terms in CO and H2 species conservation equations show that at the extinction condition the diffusion term is larger than the convection term and this is the term balances with the reaction term.

Abstract #167

Influence of Tube Dimensions on Flame Behavior near Lean Flammability Limits

Jozef Jarosinski, Artur Gutkowski

The purpose of the present study is to find reliable experimental evidence of the influence of the channel dimensions on the flammability limit. A transition from an upward propagating spherical flame to a downward propagating flat one, in a vertical

tube, is investigated in every detail. The flame behavior near the limits depends on the Lewis number, kind of fuel, mixture concentration and size of the tube. The detailed mechanism of flame quenching during its downward propagation in a lean limit mixture is also studied. The ability of such flame to propagate freely downward is analyzed. It was found out that in the range of channel dimensions from 10mm to 250mm there was no difference in flammability limits for downward propagating flames. The observed mechanism of flame extinction at the flammability limit conditions was as follows. For the limit mixture concentration the flame becomes plain and its propagation velocity is close to limit laminar burning velocity for downward propagating flames. Further reduction of mixture concentration would reduce laminar burning velocity below the limit value with following flame extinction near the wall. After some time the flame loses its contact with the tube walls and is floating freely in the central part of the tube. The residual flame with hot gases behind it is finally driven to extinction by differential buoyancy which forces cooler product gases ahead of the flame.

Abstract #173

The Dynamic Behaviour of Turbulent, Premixed Swirl Flames

Christian Külsheimer, Horst Büchner, Henning Bockhorn

The physical understanding of the frequency-dependent flame dynamics on periodic disturbances is indispensable for the prediction of the formation of combustion-driven oscillations in technical combustion systems (e.g. gas turbines). It is also essential for the development of methods to prevent or to suppress periodic combustion instabilities. The results of the measurements presented in this paper will lead to a basic understanding of the formation and reaction of large-scale coherent vortex structures in turbulent flames, that are realized as drivers of combustion instabilities. In the present paper the influence of a periodic excitation of the mass flow rate - in frequency (~Str Strouhal number) and in amplitude (~Pu pulsating level) variable and well defined - on the flow field of isothermal swirl flows and on the reaction behaviour of swirl flames with different swirl intensities are investigated. The isothermal experiments led to fluid dynamical conditions (Pu/Str) that characterize the formation of ring-vortex structures in the burner near flow field. The dynamical behaviour of the investigated flames - discussed by the means of measured flame transfer functions and phase-correlated planar imaging of OH-LIPF and Rayleigh scattering - was found to be dominated by two different effects in certain frequency ranges: For moderate pulsation frequencies the detected periodic heat release rate of pulsated, premixed swirl flames is influenced by an effect that inhibits the strong entrainment of ambient medium in comparison with the corresponding steady-state flames. With increasing frequency this effect will be overlaid by the periodical formation of vortex rings entraining additionally and interfering with the combustion process.

Soot and Fullerenes in Turbulent Flames

Abstract #68

Dynamics of Solid Carbon Formation by Turbulent Combustion and Thermal Decomposition of Natural Gas

Thomas M.Gruenberger, Mohammad Moghiman, Phil J. Bowen, Nick Syred

This paper investigates the formation process of solid carbon particles in turbulent flows within fuel-rich natural gas flames. Research on carbon formation from simple hydrocarbons under real process conditions and harsh environments allows novel insights into the general understanding of soot formation. Experimental work was carried out on a small-scale gas furnace based on the design of a modern carbon black oil furnace. The combustion system investigated is fired by a non-premixed, swirl stabilised, confined methane-air flame. The study comprises establishing conditions under which the production of solid carbon particles takes place, and progressing this towards quantification. A large number of process parameters have been investigated, and the relative role of incomplete combustion and thermal decomposition in the process of carbon particulate formation has been illustrated. Maximum solid carbon formation was found to be realised at maximum air temperature and maximum furnace temperature. Experimental investigations, using carbon particle concentration measurements and gas analysis showed that only slightly fuel rich conditions are governed by incomplete combustion only, whereas richer combustion systems are governed by thermal decomposition processes. Both processes are found to be strongly temperature dependent, whereby increase in temperature reduces particle production in the former process however enhances it in the latter. First attempts to simulate the simultaneous processes of incomplete fuel combustion and fuel decomposition in turbulent combustion systems, using a novel combination of a chemical kinetics model and a standard soot model, indicate reasonable agreement with experimental data.

Abstract #84

Numerical Investigation of Combustion and Soot Formation Processes in Turbulent Nonpremixed Flame

Hoo-Joong Kim, Yong-Mo Kim

In order to incorporate the soot formation and oxidation processes, we employed the two-variable approach and the related source terms are modeled to represent the soot nucleation, coagulation, surface growth and oxidation. For the simulation of the axi-symmetric turbulent reacting fflows, the pressure-velocity coupling is handled by the pressure-based finite volume method. The laminar flamelet model is adopted to account for the turbulence-chemistry interaction as well as to calculate the thermochemical properties and the soot source terms based on the detailed chemical kinetic model. The numerical and physical models used in this study successfully predict the essential features of the combustion processes and

soot formation characteristics in the turbulent nonpremixed flames.

Abstract #88

Hydrocarbon Combustion: A Better Technique for Large Scale Production of Fullerenes

Mohamed Hammida, Antonio Fonseca, Paul A.Thiry, Janos B.Nagy

Abstract The fullerenes are a new family of spherical carbon molecules (denoted Cn). They represent the third form of carbon after diamond and graphite. The synthesis of fullerenes in large quantities and at low prices is an industrial and commercial matter of utmost interest. In this study, we present an undeniable proof that the method of fullerenes synthesis by hydrocarbon combustion in rich mixture is the best technique for the fullerenes production at industrial scale. In an attempt to optimize fullerenes synthesis by hydrocarbon combustion, we carried out 185 flames by systematically varying all flame parameters in their feasible fields of variation. The flame parameters are: pressure, gas velocity, nature and percentage of inert gas, richness C/O and nature of hydrocarbon. Modifying these parameters allowed us to thoroughly analyze the profiles of fullerenes production, fullerenes yields (%Cn) in the soot, the mass ratio C70/C60 and the %Cn relating to various fullerenes. These profiles enabled us to describe completely the effect of the temperature of the flame on the fullerenes formation by combustion. In particular, this research shows that C60 behaves as a kinetic product at very high temperature flame. As far as fullerenes of higher molecular weight (C70, C76, C78, C80, C84, C86 and C90) are concerned, they are formed mainly under low flame temperature conditions. In addition, this research gives strong quantitative results of great economic and industrial importance.

RAMAC I

Abstract #184

Ram Accelerator Operation at 15 to 20 MPa Fill Pressure

Christopher Bundy, Carl Knowlen, Adam P. Bruckner

An investigation of the experimental conditions which permit ram accelerator operation at fill pressures of 15 MPa and higher is reported. Titanium alloy projectiles at entrance velocities as low as 1200 m/s were successfully started in propellants at fill pressures of 15 MPa, and achieved continuous acceleration in two-stage experiments with propellants at fill pressures up to 20 MPa in the second stage, the highest operating pressure achieved to date in any ram accelerator. Due to real gas effects on the acoustic speed of the propellant, the throat-to-bore diameter ratio of the projectiles needed to be reduced from the nominal value of 0.760 to 0.600 in order to enable operation at pressures greater than 15 MPa. The average acceleration achieved in these experiments was lower than that predicted by the real-gas calculations of the one-dimensional quasi-steady control volume model. The data analyzed indicate several factors that may account for the discrepancies between theory and experiment.

Abstract #168

Compressibility Effects of Unreacted Propellant on Thermally Choked Ram Accelerator Performance

P. Bauer, C. Knowlen, C. Bundy, A.P. Bruckner

The analysis of subdetonative ram accelerator performance was based on one-dimensional modeling of the flow process that propels the projectile. At moderate initial pressure, namely up to 8 MPa, the real gas corrections, based on a virial-type equation of state of the combustion products yielded a large increase in the value of the non-dimensional thrust as a function of the flight Mach number. The set of one-dimensional conservation equations this modeling is based on requires the knowledge of a series of thermodynamic parameters that can be provided by the classical thermodynamic functions. However, some further numerical and analytical treatment is needed and it is detailed in this paper. At higher initial pressures, i.e., beyond the range of 10 to 12 MPa, a further refinement of the modeling consists in taking into account the real gas corrections for the initial state. It turns out that the Redlich-Kwong equation of state is a pertinent choice. For instance, using this equation of state for the calculation of the sound speed provided a slightly higher value of the sound speed, yielding a lower Mach number. A better agreement with the experimental data was obtained in this case. These data were obtained with the ram accelerator facility at the University of Washington. This setup is designed for high-pressure ram accelerator operations, i.e., as high as 20 MPa. The corrections to the aerothermodynamic equations that were elaborated in this paper are totally general and can be applied to any EOS. This more accurate model could better predict the

projectile acceleration of the thermally choked propulsive mode involving propellant mixtures at a high initial pressure.

Abstract #112

Effect of a Suspension of Magnesium Particles on the Detonation Characteristics of Methane-Oxygen-Nitrogen Mixtures at Elevated Initial Pressures

Bernard Veyssiere, Olivier Bozier, Boris Khasainov

Addition of magnesium particles to gaseous propellant mixtures used in Ram accelerators is capable, under certain conditions, to increase their performances. This is one of the causes to explain why in experiments with magnesium projectiles, acceleration of projectiles up to velocities higher than the CJ detonation velocity of the gaseous propellant mixture can be observed. Thermodynamic calculations indicate that increase of detonation velocity in a proportion comparable to experimental observations requires to add, at least, a concentration of 2000 g/m3 of magnesium particles to the gaseous mixture (methane - oxygen - nitrogen mixtures initially at 300 K and 40 bar). Gasdynamics calculations show that modifications of detonation performances strongly depend on the diameter of particles. Augmentation of the detonation velocity can be obtained only with sufficiently small particles (2μm). On the opposite, larger particles (20μm) promote a decrease of the detonation velocity. With intermediate size (5μm or 10μm) particles, only a limited augmentation of detonation performance can be obtained, depending on the composition of the gaseous mixture.

Abstract #145

Visualization of Burning Flow Around the Projectile in Ram Accelerator by Coaxial Simultaneous Shadow/Direct Photograph

Tomoaki Yatsufusa, Shiro Taki

A rectangular bore ram accelerator has been developed since 1993 in Hiroshima University. This ram accelerator is designed to visualize the inside of the ram accelerator. The experiment was executed with the methane-oxygen-carbon dioxide mixture filled in the ram tube. We observed the combustion flow field around the projectile traveling with the velocity slower than that of the C-J detonation of the mixture, using the instantaneous shadow photograph and the direct photographing. The direct photographing can detect the light emission from the combustion, so that we can obtain the information of the position and intensity of the flame. Pressure history at the observing point is also useful for understanding the flow field. In the previous experiment, it has been cleared that the flame in the boundary layer on the leading wedge of the projectile is observed when the projectile velocity is relatively low. This flame is the remainder of the ignition process. In the present experiment, we cannot see any luminous fragment of the flame in the boundary layer at the leading wedge from the direct photograph. Therefore, it is assumed that the reaction of the combustion around there is very weak.

Laminar Flames IV

Abstract #69

Reattachment of Lifted Flames in Laminar Propane Jets

Jongsoo Lee, Suk Ho Chung

Reattachment characteristics of laminar lifted flames in partially premixed jets are studied for propane fuel mixed with air. As flow rate decreases, liftoff height decreases nonlinearly and the flame reattaches to a nozzle at a certain liftoff height. Using a jet theory by taking into account virtual origins, it is predicted that the flow velocity along the stoichiometric contour has a maximum value near nozzle. With these velocity characteristics, it is shown that reattachment mechanism can be explained by the balance between the propagation speed of a tribrachial flame and flow velocity. Predicted displacement speeds at reattachment and liftoff agree qualitatively well with experimental findings.

Abstract #109

Surface Instability and Droplet Pinch-Off for Liquid Films and Filaments

Dirk Meinköhn

For an investigation of combustion instabilities in liquid-fuelled rocket propulsion, a physically sound description of droplet pinch-off from liquid parent bodies represents a key element of any model which is intended to be predictive. Droplet pinch-off can be obtained by way of a distinguished limit of ordinary hydrodynamics. A process of asymptotic matching then joins the initial states of the injected liquids with the final spray states. By investigating the evolution of deformations in 2-d liquid membranes it can be shown that only for the case of unsupported liquid 1-d filaments droplet pinch-off is possible. This is due in this case to the effect of intrinsic curvature going to infinity as the filament thickness vanishes, whereas for planar films any neck tends to get smoothed out. The particular importance of cylindrical filaments for droplet formation is borne out by many experimental observations.

Abstract #122

Three-dimensional Ignition and Flame Propagation Above Liquid-Fuel Pools: Computational Analysis

J. Cai, F. Liu, W.A. Sirignano

Ignition and flame propagation above a pool of liquid alcohol fuel initially below the flash-point temperature is considered by means of three-dimensional, unsteady computational fluid dynamics. Flame spread is opposite to the direction of an incoming forced air stream that can be augmented by natural convection. The effects of air-duct side walls and of the pool edge produce span-wise curvature in the flame front. The flame edges result in heat losses but also allow oxygen to more readily feed the flame. Pulsating and uniform spread regimes are studied. The coupling with liquid flow occurs through vaporization, liquid convective heating, varying surface tension

due to its temperature dependence, buoyancy, and viscous shear. Some comparisons are made with the experiments of H. Ross and F. Miller at NASA Glenn.

Turbulent Spray and Jet Flames I

Abstract #177

Turbulence and Velocity Induced by Combusting Impinging Jets

G.M. Abu-Orf, Y. Zhang, B.E. Launder, K.N.C. Bray

LDA studies of the turbulence and velocity induced by combusting jets have been carried out. Extensive and detailed flow characteristics of two combustion modes (disc and ring flames) under identical nozzle flow conditions have been measured. The data have shown dramatic difference in flow structures between the two combustion modes. Clear evidence has been provided by the measurement to prove the previous conjecture that the ring flame occurs on the opposite ramp side to the stagnation region of the radial velocity profile. The measurements also reveal that combustion can only occur beyond the maximum wall jet velocity layer and further away from the plate surface in the case of the ring flame jet.

Abstract #192

Local Extinction and Reignition in Nonpremixed Turbulent Jet Flames: A View Using the One-Dimensional Turbulence Model

John C. Hewson, Alan R. Kerstein, J.H. Chen

Localized extinction and reignition are studied in turbulent nonpremixed CO/H2/N2 jet flames using the one-dimensional turbulence (ODT) model. Within the ODT model extinction occurs through the multiplicative increase in scalar gradients leading to heat loss rates exceeding heat release rates, and reignition occurs through interaction between extinguished and burning flamelets. Triple flames can not occur within the limits of the ODT model. In ODT, both the extinction and the rate of reignition are related to the scalar dissipation rate. In the latter case, the correlation between reignition and scalar dissipation rate arises because burning flamelets are mixed with extinguished flamelet more rapidly. That is, flames with overall larger dissipation rates have greater extinction and more rapid reignition. The correlation of both extinction and the flame-flame interaction with the scalar dissipation rate implies that flame-flame interactions may be the significant mode of reignition, relative to triple flame propagation, where extinction is significant, though this is not substantiated in the present work.

Abstract #199

Assessing the Risk of Spontaneous Ignition of Coal and Biomass

Y.S. Nugroho, A.C. McIntosh, B.M. Gibbs

Coal and biomasses are often stored in stockpiles over long periods of time. These solid fuels undergo exothermic reactions

with oxygen, even at ambient temperatures, and this can lead to spontaneous ignition of the fuel within the stockpile. Coal or biomass users therefore require immediate methods for assessing the self-heating potential of these fuels since they are not all equally susceptible to spontaneous combustion. In this study kinetic ignition parameters on low temperature oxidation of coals or biomass, determined by the crossing-point method, have been used in conjunction with the Frank-Kamenetskii theory to develop a risk index for spontaneous combustion. The rate of heat release at low temperatures, determined from simple oven heating tests on a particular fuel, can then be used together with the risk index to assess the propensity of a coal or biomass to spontaneous ignition in a stockpile. It was found that a low rank coal has greater propensity to self-ignition than a high rank coal. Biomass however presents the greatest risk of spontaneous combustion. Particle size has a significant influence on the self-heating behavior of the fuel. For small piles, fine particles show a strong tendency to self-ignition, whilst for large piles, a greater risk is encountered by large particles.

RAMAC II

Abstract #193

Investigation of the Ram Accelerator Projectile In-tube Stability

Liu Sen, Bai Zhiyong, Carl Knowlen, Adam P. Bruckner

Analytical and numerical computations of the aerodynamic forces on ram accelerator projectiles operating in the thermally choked propulsive mode are being carried out to investigate their in-tube stability characteristics. Fins or tube rails have been used in experiments to keep the projectile centered as it accelerates through the tube. Small perturbations to the projectile orientation (canting and/or translation) result in a pressure imbalance which produces both a side force and torque. If the projectile has fins, then these aerodynamic forces are counteracted by the reactions of the fins on tube walls. Erosion induced by high-speed fin/tube wall friction eventually wears the fins down which leads to increased canting and further distortions to the pressure field. Ultimately the projectile is canted so far to one side that the corresponding minimum flow passage area (i.e., throat area) becomes too small to accept the required mass flow and an unstart occurs. The purpose of this investigation is to determine the magnitude of the destabilizing forces arising from the translation and canting of two-dimensional and axisymmetric projectiles. These results could facilitate designing functional projectiles that are aerodynamically stable in the reactive flow field of the thermally choked ram accelerator, thus minimizing the need for guiding fins or rails.

Abstract #76

Numerical Study of the Effect of Shock Strength on the Normal Start and Unstart Process in a Superdetonative Mode Ram Accelerator

Guee-Won Moon, In-Seuck Jeung, Jeong-Yeol Choi, Friedrich Seiler, Gunther Patz, Gunter Smeets, Julio Srulijes

Ram Accelerator facilities offer major benefits for hypersonic research. ISL has developed a ram accelerator facility that bypassed the gasdynamic transition directly from subdetonative to superdetonative ignition. Experiments in the ISL's RAMAC 30 with same condition except for projectile surface material demonstrated that there is an important ignition mechanism which is strongly related to the aluminium projectile surface's friction, heat conduction, and combustion. To understand the combustion mechanism in a superdetonative mode ram accelerator according to the mixture strength, numerical simulations were done for ISL's RAMAC 30 experiments by imposing external ignition energy on the combustor section to initiate detonation. Among the experimental cases with an aluminium projectile shot 224, shot 225 and shot 228 were selected as test cases. In case of shot 225(2H2+O2+5CO2) the edge of the separation bubble acted as a flame front around the projectile surface, while detonation was formed near the tube wall where the strong reattached shock was reflected. Also, strong reattached / reflected shock created a second separation bubble at the projectile surface. Accordingly, the whole flame structure became stable and continuous acceleration was plausible. In case of shot 228(2H2+O2+4CO2) the separation bubble near the shoulder greatly enlarged and moved upstream. Furthermore, the combustion wave, basically driven by a very strong shock-induced combustion, also traveled upstream in front of the projectile, called unstart, followed by a strong projectile deceleration. Numerical results of shot 224(30bar) and shot 225(40bar) showed normal acceleration with similar flame structure even though the magnitude of acceleration was different according to the fill pressure.

Abstract #16

Dynamics of Laser-Driven Blast Wave Generated in Space Propulsion Configuration

Akihiro Sasoh

A system of laser propulsion device which can be applieed as a ram accelerator, PDE or zero-start launcher has been developed. Measurements of the overpressure and emission spectroscopy were conducted. Those diagnostics lead better understanding of the relation between the blast wave behavoir and measured propulsion performance.

Abstract #198

Critical Condition for Stabilized Chapman-Jouguet Oblique Detonation Waves Around Hypersonic Bodies

Jiro Kasahara, Takakage Arai, Akiko Matsuo, Nobutaka Akai, Kouki Takazawa

Five-mm-diameter projectiles, whose speed was beyond the Chapman-Jouguet (C-J) detonation speed, were fired into mixtures containing stoichiometric hydrogen-oxygen gases plus argon diluents. The flowfield around the projectile was visualized using a CCD camera. We measured the minimum normal velocity components of detonation waves around the projectiles and the effective curvature radius of a bow detonation wave near the projectile tip. From these experimental results we concluded that the steady-state C-J detonation wave is stabilized around a projectile when the effective curvature radius of the bow detonation wave is larger than 8.6 times of the detonation cell size. The critical cell size is about 1.2 mm at 5-mm projectile diameter. That is, the steady-state C-J detonation wave is stabilized around a projectile when the projectile diameter is larger than roughly 4 times of the detonation cell size. We performed the experiments in a stoichiometric hydrogen-oxygen gas mixture with argon diluents (diluents' mole fractions were varied from 0.2 to 0.6), at initial fill pressures from 0.5 to 1.1 atm, and room temperature of 291 4 K. The projectiles had a conical nose of 120-degree open angle, 5 mm in diameter, and were made of polyethylene. The projectile velocity was ranged from 1.97 km/s to 2.81 km/s, but it was always faster than the C-J velocity, to ensure an overdriven stabilized detonation condition on the projectile nose.

Abstract #95

Ram-Acceleration Enhancement through Projectile and Staging Design

Yuichiro Hamate, Akihiro Sasoh, Kazuyoshi Takayama

A ram accelerator is a device that can launch a relatively heavy projectile. Various investigations have been conducted to achieve a high muzzle velocity in this device. A long ram acceleration tube and a high acceleration rate can increase the muzzle velocity. However, in practice the facility length is often limited. Therefore, in order to achieve high muzzle velocity, the present paper tries to increase the acceleration level. Bruckner et al. discussed the effect of unsteadiness in calculating thrust. They evaluated unsteady terms in each conservation equation and concluded that the effect of the projectile acceleration, which was lower than 40,000 g, on the thrust could be negligible. Thus, quasi-steady-state analysis has often been used to predict thermally choked ram accelerator performance. However, operational characteristics at higher acceleration have not been well studied, thereby requires further investigations. Investigation of high acceleration operation using reduced mass projectile is in progress at Shock Wave Research Center. The mass of the projectile could be reduced by sophisticatedly

lathing inner shape of the projectile, which was referred to as "open-base" projectile. Single stage operations were conducted in a reliable starting mixture, 2.8CH4+2O2+5.7N2. Depending on the entrance velocity, delayed start was observed, in which the ram acceleration was established after some time lag. By increasing the entrance velocity over 1.3km/s, the successful immediate ram acceleration was obtained.

Flame Interactions / Explosions

Abstract #150

Scale Effect on Recirculation Zone of the Bluff-body Burner with Concentric Jets

Jing-Tang Yang, Yu-Ping Kang

The scale effect on recirculation zone behind a disc-type bluff-body burner was experimentally investigated with a Schlieren photography system, fine-wire thermocouples, and a planar laser-induced fluorescence spectroscopy. Combustion regime diagrams were established by adjusting the fuel-to-air velocity ratio and the fuel-to-air momentum ratio for four air flow blockage ratios (21%, 40%, 67%, 82%). Experimental results show that the transition from jet-like flame to lift-off flame was highly sensitive to the blockage ratio. The range of the annular-air velocity/momentum corresponding to the lift-off flame broadened with the increasing blockage ratio. For central-jet dominated flame, the blockage ratio and velocity ratio were both the important factors to bring on the alteration of the high temperature region. While the fuel-to-air velocity ratio increased, the temperature of the central jet in recirculation zone was still low but the high temperature region on the outer shear layer of air-driven vortex moved to upstream, and was eventually filled with inside of recirculation zone. This phenomenon was more noteworthy as the blockage ratio got larger. Moreover, when the blockage ratio increased, the main combustion zone moved regularly toward the inner side of the recirculation zone and the hydroxyl radical signal intensity became powerless, just as that of increasing fuel-to-air velocity ratio. The transition of combustion zone was apparently dominated by the momentum ratio.

Abstract #208

Structural Characteristics and NOx Formation in an Oscillating Stagnation Flat Flame

Yei-Chin Chao, Yau-Wei Huang, Guan-Ban Chen

Motivated by the previous significant NOx reduction results of an acoustically excited jet flame, the effects of periodically varying strain rates on the structural and NOx formation characteristics of an oscillating flat flame are studied numerically and experimentally. The flat flame is stabilized in the oscillating stagnation flow field generated by jet impingement on an oscillation plate. Unsteady strain rate is induced by periodically oscillating the flat plate relative to the impinging jet using a precision shaker. The flame parameters from flame images, thermocouples and NO-LIF images at

prescribe phases are used to compare with numerical results. The SPIN code in cooperated with GRI mechanism is used for numerical simulation and the unsteady term is solved by the second-order implicit scheme. Increasing flame stretch causes decreasing peak temperature and NO production decreases. The width of the NO profile becomes narrower with an increase in stretch owing to the increased velocity gradients. For the low-amplitude oscillation case, the relative OH concentration and Tmax peaks in a cycle lag behind the lowest strain rate, 90o, by about 5 ms and the structural and NO emission characteristics of the flame are relatively insensitive to the variation of the strain rate near the highest stain rate in a cycle. For the high amplitude oscillation case, after the lowest strain rate in a cycle, the "accumulation effect" becomes prevail in the flame and the flame becomes rather insensitive to the variation of the strain rate and stays in high values for OH, Tmax and NO throughout the rest of the cycle.

Abstract #141

Dynamic Response of a Non-Premixed Flame to Electric Field Forcing

Ben A. Strayer, Derek Dunn-Rankin

Combustion control is a relatively new and promising concept for achieving and maintaining optimal performance of combustion systems. For control applications, it is important to identify the actuator in the loop. Acoustic actuators (i.e., loudspeakers), pulsed fuel jets, pulsed air jets, and fuel/air mixing have all been used to modify the combustion process in response to measured output. This paper describes the use of an electric field, acting on flame ions, as the control actuator for small diffusion flames. Furthermore, the work examines the dynamic response of the small flame, as measured by its temporally varying heat release (CH chemiluminescence). We find that the chemiluminescense behaves very much as a simple second order system (e.g., as a damped spring-mass) when the flame is forced by an electric field. The electric field acts on the flame ions, setting them into motion. The ions collide rapidly and often with neutral molecules, which, in turn, sets the neutrals into motion. The net result is a body force on the gas. It takes time for this body force to produce a flow that actually affects flame behavior, and it is this time delay that accounts for the relatively slow system response. Nevertheless, with a linear second order model of the system, it is possible to design a fast controller. The full paper describes the flame experiment, the theoretical control development, and the control implementation on a small capillary-fed non- premixed flame.

Abstract #191

Quenching Distance Measurement for the Control of Hydrogen Explosion

Hong Jip Kim, Seong Wan Hong, H.D. Kim, Seung Yeon Yang, Suk Ho Chung

The characteristics of quenching distances for control of hydrogen/air/steam mixture combustion are experimentally

investigated. The quenching distances of various hydrogen/air mixtures without steam over a range of initial pressures are measured. Also, those of stoichiometric hydrogen-air mixtures with various steam mixture ratios over a range of initial pressures are measured. The experimental results of each hydrogen/air mixture show that the quenching distance near atmospheric pressure is inversely proportional to the initial pressure of combustion chamber. The stoichiometric hydrogen/air mixtures without steam have the minimum quenching distance at atmospheric pressure, too. For the stoichiometric hydrogen/air/steam mixture, the quenching distance is more or less increased because of the effect of the steam as inert gas and heat sink and the effect of the HO2 third body reaction. Such experimental results of quenching distance measurement establish that the quenching meshes proposed for the control of hydrogen combustion under severe accident in the nuclear power plant are reasonably available.

Abstract #99

Dust-Air Mixtures Spreading in Branched Ducts

Rudolf Klemens, Pawel Kosinski, Piotr Wolanski, Victor Korobeinikov, V.V. Markov, I.S. Menshov

The phenomena of dust explosions are well known in industry, where various kinds of dust, like metallic or organic ones, are used or produced. Having such a medium dispersed in the surrounding air, a combustible mixture is formed. It may be ignited by any source of energy, and the explosion might lead to serious damages or casualties. The problem has been investigated successfully by many researchers. Nevertheless, the results of the experiments are usually limited to simpler cases, like the explosions in straight channels or vessels. In reality, the channels are often branched, and there is a hazard that such an explosion may propagate in different directions. The computer simulations of dust-air explosions, although not well developed nowadays, might help in analysing many physical phenomena and mechanisms responsible for the processes. The paper presents results of numerical experiments performed for two geometries, where the influence of various parameters have been examined. The objective has been to show how the CFD may serve as a tool for predicting and examining the processes of dust-air mixtures explosions in complex geometry systems.

New Devices and Methods

Abstract #15

The Application of Spontaneous Vibrational Raman Scattering for Temperature Measurements in High Pressure Laminar Flames

T. S. Cheng, T. Yuan, C.-C. Lu, Y.-C. Chao

Ultraviolet (UV) spontaneous vibrational Raman scattering is used for temperature measurements in premixed methane/air flat flames burning at 1 - 5 atm. Temperature measurements are made by spectral-fit of the theoretical spectra to the measured N2 Q-branch spectra. The Raman-measured temperatures agree well with the thermocouple-measured temperatures. The

linewidths (full width at half maximum; FWHM) of the trapezoidal slit function in flames at 1 - 5 atm are used to extrapolate the linewidths for pressures up to 30 atm. The calculated theoretical spectra indicate that the spectral-fit method can be used to determine flame temperature at conditions of 30 atm and 2300 K with an adequate accuracy.

Abstract #81

Appropriate Use and Basic Characteristics of Electrostatic Probes

Toshisuke Hirano, Junichi Furukawa

Electrostatic probes are promised diagnostics for combustion measurements because of excellent time and spatial resolution. However, only limited researchers have successfully used electrostatic probes to obtain the meaningful information. The objective of this paper is for helping combustion researchers to resolve the issues that they face at the use of electrostatic probes. Thus, fundamental knowledge for appropriate use and basic characteristics of electrostatic probes on the basis of currently available information have been introduced. The control mechanisms of ion behavior surrounding the sensor of an electrostatic probe is discussed. The thickness of the ion diffusion region is indicated to be much smaller than the probe dimension. Also the sheath is shown not to influence the ion current records if the probe potential is kept in an appropriate range. It is indicated that the reliability of an electrostatic probe appropriately used is the same as that of the hot wire anemometer. Based on the fundamental knowledge of ion collection by a conducting body in a slightly ionized high-density gas, the appropriate probe structure and electric circuit for ion collection are introduced.

Abstract #86

NO- and HC- Removal by Non-Thermal Plasmas

I. Orlandini, U. Riedel

A promising method of exhaust-gas cleaning is the use of pulsed corona discharges. In these devices, short pulses at high frequency produce radicals for a subsequent transformation of toxic pollutants (NOx, SO2, CxHy etc.). For a better understanding and optimization of possible applications of this technique it is necessary to develop models for the underlying physical and chemical processes which are responsible for the removal of pollutants. In this work, we have theoretically investigated the removal of NO and the effect of ethane and ethene on NO removal by non-thermal plasma discharges at low temperature (373 K) and at atmospheric pressure. The model takes into account production of radicals in every discharge pulse and subsequent removal of NO and HC by radicals. For this purpose, a detailed chemical model has been developed consisting of 96 species and 1187 elementary reactions. The results of our numerical simulations show good agreement with experimental data published in the literature.

Abstract #205

Hydrogen Oxidation and Ignition Development by Nanosecond High-Current Discharge

D.V. Zatsepin, S.M. Starikovskaia, Andrei Yu. Starikovskii

Influence of the electric discharge on the reaction dymanics and ignition delay time were investigated experimentally and numerically for different hydrocarbon-air mixtures. The proposed mechanism of chemical kinetics description in essentially nonequilibrium conditions gives a possibility of the quantitative analysis of vibrationally nonequilibrium processes and their influence of a whole chemical kinetics in the system. It was shown that in the conditions of a pulsed high-current nanosecond discharge the role of the processes with participation of vibrationally excited components is principal an significantly influences the kinetics in the system. The results obtained in the present work show us a possibility of utilizing the non-equilibrium gas discharge for a wide control of hydrocarbon-air mixtures ignition and combustion. This control may be effective in the wide range of gas parameters: pressures, temperatures and equivalence ratios. It was shown that sensitivity of the ignition delay time with respect to the non-equilibrium excitation increases with pressure. The induction time sensitivity increases for lean fuel-air mixtures with compare to the stoichiometric ones.

Abstract #30

Laminar-to-Turbulent Flame Transition Initiated by Generation of Instabilities in an Ignition Kernel

Eugene Gordon, Yurii Moskvin, Vladislav Zelenov, Alexander Shteinberg

A new concept of accelerating the laminar-to-turbulent flame transition in a cylinder of an internal combustion engine (ICE) is proposed, thus leading to a reduction in the total time of burning. The effect is achieved by transiently attacking the ignition kernel with a high-frequency (HF) electromagnetic radiation pulse that is quasiperiodically modulated with 10-1000 kHz, being close to resonant frequency of breathing the ignition kernel. Radiation is absorbed by electrons existing only inside the ignition kernel during the initial stage of its development, i.e. 50-500 microseconds after ignition. Due to thermal inertia, the medium perceives the oscillations on the frequency of modulation, whereby the kernel becomes unstable and splits into separate fractions. This causes transfer from laminar to turbulent bulk combustion. The technique proposed is of an especially great importance for a lean-burn ICE that is normally characterized by low combustion temperature and hindered transition to fast turbulent flame propagation.

Heterogeneous Combustion

Abstract #125

Combustion of Supersonic Metallic Spheres

A.J. Higgins, D.L. Frost, C. Knowlen, F. Zhang, S.B. Murray

Experiments have been carried out in which reactive metallic spheres were accelerated to supersonic speeds within an aeroballistic facility. The conditions under which the spheres ignited due to aerodynamic heating were determined as a function of sphere material and the gaseous environment. Aluminum, magnesium and zirconium spheres ignite and burn due to aerodynamic heating alone in pure oxygen at elevated pressure, but not in air. Only zirconium spheres sustained combustion after a transition from oxygen to air. Once ignited, the spheres did not experience a significant reduction in drag (not more than 20%). It is likely that the self-combustion of a non-spherical projectile (e.g., one with a conical shape) with a larger surface area available for the thrust force would have a greater influence on the projectile aeroballistics.

Abstract #227

Formation and Thermal Decomposition of Solid Carbon Particles during Pyrolysis of Carbon Suboxide behind Shock Waves

G.L. Agafonov, M. Nullmeier, P.A. Vlasov, J. Warnatz, I.S. Zaslonko

The ability of carbon to form clusters in the gas phase at high temperatures has been known for a long time. The appearance of the laser-vaporization supersonic technique made it possible to study the properties of carbon clusters in detail as they grew through the size range of 40 to 100 carbon atoms in cluster. The other promising approach to study the formation and thermal decomposition of carbon clusters and solid particles is the shock tube technique. The experiments with carbon suboxide C3O2 thermal decomposition behind shock waves demonstrate the formation of soot-like solid carbon particles with the maximal yield attained at the temperature of 1800 K (the mixture of 0.2% C3O2 in Ar, p = 5.4 MPa) and at the temperatures of 2800-3000 K (the mixture of 1-2% C3O2 in Ar, p = 2.0 MPa). In the current work, the results of the kinetic modeling of thermal decomposition of carbon suboxide and formation, transformation, and thermal decomposition of fullerene-like and soot-like solid carbon particles formed behind incident and reflected shock waves (the two-step heating technique) are presented. It was revealed that the second high-temperature peak of the solid carbon particle yield has a specific fine structure, which depends on the prehistory of the process of carbon particle formation behind incident shock wave.

Secondary Combustion

Abstract #56

Promotion of Secondary Combustion Phenomena by Geometrical Constrains in the Course of Non-Ideal Explosions

B.E. Gelfand, A.M. Bartenev, L.H. Josephson, M. Banks, S.V. Khomik, S.P. Medvedev, A.N. Polenov, P. Williams

The large scale tests and numerical calculations presented in the frame of the current work aimed the analysis of the flowfield generated by non-ideal explosives in the presence of geometrical constrains such as the cone reflectors. The given purpose assumes the search of the configuration mutual arrangement of HE charge and reflecting element ensuring the maximal influence on the basic parameters of shock (explosive) waves (intensity, duration, structure, impulse) in the course of explosion. A mechanism of after-burning initiation was proposed. The work performed brings to a conclusion, that placing specially chosen reflecting surface nearby the non-ideal explosive can result in effect on the process of after- burning in detonation products. The analysis presented shows the possibility of registration of this effect on the field of explosion. Established, that there exist effective distance, at which the secondary burn-out proceeds with the most completeness. This distance depends on the charge composition and the geometry of the reflector. For the standard HE (TNT-type) such dependencies were not found.

Abstract #89

Optical Temperature Diagnostics of After-Burning Phenomena in Expanded HE Detonation Products

B.E. Gelfand, M.F. Gogulya, S.P. Medvedev, A.N. Polenov, S.V. Khomik, A.M. Bartenev

The paper describes the results of experiments on emission/ temperature measurements in the course of detonation of TNT- and RDX-based high explosives. The temperature evaluation was performed by the use of double-wavelength photodiode detectors. Particular attention was given to the later stage of expansion of the cloud of detonation products. It was shown that the turbulent mixing between detonation products and surrounding air results in secondary burning (after-burning) process that is controlled by the carbon (soot) content.

Abstract #80

Mixture of Initial Reagents with Hot Detonation Products as the Subject of Studies in the Shock Tube

V.I. Tarzhanov

The way and TSD-01M facility (Tube of Spontaneous Detonation) are proposed for quantification of basic mechanisms of deflagration to detonation transition (DDT). In the case of rapid quasi-homogeneous injection of hot detonation products (HDP) from a small perforated tube into the main coaxial tube of the facility the area containing the

mixture of initial cold reagents with HDP is formed in a part of the tube. The fastest regime of combustion in the small tube, namely detonation, is chosen for attaining maximum possible rate of mixing of HDP into initial reagents. Parameters of small tube perforation (diameter of holes, number of holes, density of their location) condition three scales of turbulence, which are associated with: (i) a single jet of HDP from one hole, (ii) multiple jets of hot detonation products, (iii) the length of the created area of HDP mixture. Basic parameters of TSD-01M facility: length and diameter of the main tube - 17m and 402mm, respectively. The two types of experiments are basic ones at TSD-01M facility. Firstly, these are experiments for determination the critical initiation energy for the mixture with HDP. Secondly, these experiments are aimed at registering spontaneous processes in the mixture with HDP. All experiments study detonation transition from the mixture with HDP to cold reagents.

Multiphase Combustion II

Abstract #133

Flame Spread over Thermally Thin Layer System "Metallic Substrate – Fuel Film"

A.A. Korzhavin, V.A. Bunev, S.S. Minaev, I.G. Namyatov, V.S. Babkin

The process of flame spread over a liquid fuel film (hydrocarbons and spirits) on a foil of copper, steel or aluminium has been examined for a linear thermally thin layer system. The flame spread depends on the direction of propagation relative to the gravitational force. In the flame spread mechanism heat transfer from the products to the preflame zone plays an important role. This heat transfer can proceed due to conductivity through the metallic substrate or to free convection. Accordingly, one may identify two flame spread regimes: thermal conductive and convective ones. When environmental temperatures are higher than the lower temperature flammability limit, there can be either rapid (about 100 cm/s) flame spread through the gas phase without substantial heat exchange with the metallic substrate or slow spread (about 3 cm/s) with a key mechanism of forward heat transfer through the substrate. Together with steady-state regimes four oscillation combustion regimes were obtained, namely, combustion with transverse chaotic oscillations, combustion with transverse regular oscillations, spin combustion and combustion with regular longitudinal oscillations.

Abstract #115

Partially Premixed Combustion in Spray Flames

J. Reveillon, L. Vervisch

The objective of this work is to seek out combustion regimes in turbulent sprays, and particularly partially premixed combustion.To this end, 2D direct numerical simulation (DNS) including finite rate chemistry has been used in association with

a Lagrangian solver for the dispersed vaporizing phase. The geometry of a turbulent jet has been retained. By varying the spray properties in term of droplet density and size, many flame topologies and combustion modes are observed in the simulations. It has been shown as well that the combustion regime around a liquid spray strongly depends on the droplets size and distribution.

Abstract #169

Delayed Thermal Explosion in Inert Porous Matrix Filled with Evaporating Liquid Fuel

I. Goldfarb, V. Gol'dshtein, A. Zinoviev

Theoretical investigation of the phenomenon of gaseous thermal explosion in porous media filled with a combustible evaporating fuel is presented. An original physical model was suggested. The relevant mathematical model is studied analytically using the method of integral manifolds (MIM). It is shown that under the realistic parameter values the system behavior is explosive with long-time delays. The analytical estimation of the delay time is gained and compared with the results of the direct numerical simulations. The comparison witnesses that the accuracy of the derived estimation is quite high. A novel approach to determination of the activation energy on the basis of delay time measurements is suggested.

Detonation Hazard

Abstract #4

Hydrocarbon Gas Hydrates and Their Detonation Hazard

A.A. Vasil'ev, A.I. Valishev, V.A. Vasil'ev, L.V. Panfilova

The calculated parameters of mixtures methane-oxygen(air)-H2O and acetylene-oxygen (air)-H2O are presented from ecology and hazard points of view. The values of the critical initiation energy with reference to hydrates of methane and acetylene have been estimated. The data indicates the burning possibility of hydrocarbon hydrates in oxygen and air. As to a detonation, it is possible to speak about real explosion hazard of acetylene-hydrates, whereas methane-hydrates require the unreal large charges for initiation of detonation.

Abstract #233

Ignition of Liquid and Dust Fuel Layer by Hydrogen-Oxygen Detonation

Piotr Wolanski, Arkadiusz Kobiera

Ignition of the liquid layer and dust fuel layer by the detonation wave propagating in the hydrogen-oxygen mixture is reported. Experiments were carried out using shock tube equipped with optical quality observation windows. Schlieren system and high-speed camera were used for measurements of ignition delay, while pressure transducers provided data necessary for measurements of detonation wave velocity and pressure variation within the front of interacted detonation wave and fuel layer. Kerosene, nitroglycerine and pentryt were used as fuels. Investigation shows that the layer of liquid fuel can be

efficiently ignited by detonation wave. It was found that the ignition delay of fuel layer depends primary on detonation wave velocity and sensitivity of igniting fuels and less on layer thickness. Knowledge of behaviour of fuel ignited by detonation can be useful for evaluation of explosion hazard associated with a spill of dangerous chemicals.

Numerical Computations

Abstract #36

Fast and Accurate Flame Computations Using Detailed Chemistry and Transport

Romain Baron, Sebastien Paxion, Dominique Thévenin

Accurate simulations of flames and of their detailed structures are important from scientific, economical and ecological points of view: they are needed for fundamental research in order to improve the knowledge about laminar flame structure but also for industrial applications, since manufacturers of domestic burners have to cope with drastic regulations on pollutant emissions. Unfortunately, these simulations remain at present time very costly and everything must be done to cut down computing times. We have developed a powerful combustion code for 2D and 3D gas flame computations. Complex geometries can be handled with dynamically adapted multi-level unstructured grids. With a view to meet the requirements of the gas burner industry, a low-Mach number approximation is used in order to circumvent the usual CFL restriction. The physical terms are provided by an elaborate interface including different levels of accuracy. Detailed models are available to describe chemistry and diffusion, but it is also possible to use simplified, reduced models for faster simulations. Good results have already been obtained with detailed chemistry and transport, starting from a very rough initial solution, on an idealized household burner configuration. The chemistry reduction method we have implemented will enable, in the near future, much faster computations. Thanks to the expected speed-up, we will tackle new applications, including real 3D simulations and automatic design optimization. Finally, unsteady simulations will be carried out in order to demonstrate the possibility of using this code for turbulent flames, in particular in the frame of Large-Eddy Simulations.

Abstract #196

Numerical Simulation of Compressible Reactive Viscous Flow in Complex Geometries

Marcello Manna, Francesco S. Marra, Andrea Pascarelli

The work presented here is mainly concerned with the ability to capture the correct physical behaviors of an inviscid flow model studying Detonation and Deflagrations to Detonations Transition (DDT). Inviscid and viscous numerical results concerning the detonation front propagating over a sudden expansion and in an obstacle filled channel are presented. The analysis provides a transparent and revealing qualitative and quantitative understanding that the usual arguments employed

to support the validity of the inviscid flow model become increasingly weaker in a reactive environment.

Transonic and Supersonic Combustion

Abstract #128

Combustion in a Transonic Flow with Large Axial and Transverse Pressure Gradients

Jingshen Cai, Olgu Icoz, Feng Liu, William A. Sirignano

A computational code has been developed for solving the full compressible Navier-Stokes equations with multiple species and chemical reactions. A k-omega turbulence model is employed. Fuel is injected at the entrance to a curved turbine passage amidst the main flow of heated air and combustion products exhausting from the main combustor. The code is used to study the flame structure in a transonic flow under the influence of large axial and transverse pressure gradients typical of conditions in a turbine passage. It is found that the transverse pressure gradient does not directly affect the steady-state flame structure significantly. However, the velocity nonuniformity due to the transverse pressure gradient thickens the flame in the low speed region and increases the combustion rate globally compared to the situation in a straight channel. Computational results will be presented on the ignition and flame structures under conditions as determined by inflow conditions, curvature of the channel, and variation of cross-sectional area. Comparisons with previous results for laminar flows and for algebraic turbulent models will be made.

Abstract #48

Stability of Underexpanded Supersonic Jet Flames Burning H2-CO Mixtures

C.B. Devaud, J.B. Kelman, J.B.Moss, C.D. Stewart

A wide variety of process gases, manufactured and utilised in the chemical industry, are stored and transported at high pressure. One such gas attracting increasing interest is 'syngas', comprising a mixture of carbon monoxide and hydrogen, whose venting or accidental release may pose a significant fire and explosion hazard. The precise nature of the hazard will depend, to a significant extent, on the stability of any jet flame resulting from the underexpanded fuel release. It has been established experimentally, for example, that both natural gas and hydrogen discharges, through circular orifices larger than a critical diameter, sustain stable lifted flames irrespective of the reservoir pressure driving the release. At smaller diameters, however, stable burning will only be achieved at operating pressures higher than a particular, diameter-dependent, threshold. In the case of pure hydrogen, the critical diameter is approximately 1 mm, whilst for natural gas, predominantly methane, the values is ~30 mm. Given the wide disparity of these values, the behaviour of multicomponent mixtures involving hydrogen is then less readily predicted. Large differences in the combustion characteristics of mixture components - for example, in burning velocities and

flammability limits - may be further compounded in extensively lifted flames by differences in molecular weights and, hence, transport properties. The present paper describes an experimental and computational investigation of the stability of underexpanded CO-H—2 jet flames over a range of driving pressures and mixture compositions.

Monday, July 30			
	210 Kane Hall	220 Kane Hall	120 Kane Hall
8:15 AM	Opening Ceremony -- *Kane 120*		
8:55 AM	Cellular Structure I	Explosion Physics	Premixed Turbulent Flames I
10:10 AM	Coffee Break		
10:30 AM	Plenary Lecture: D. Bradley -- *Kane 120*		
11:20 AM	Cellular Structure II	Gas Explosions	Premixed Turbulent Flames II
12:35 PM	Lunch Break		
2:00 PM	Detonation Structure	Condensed Phase Explosions/Detonations	Dust and Metal Containing Flames
3:15 PM	Break		
3:40 PM	Cellular Structure III	Detonation Limit/Failure	Gasless and Dust Containing Flames
4:55 PM	Sessions Adjourn the for day		
7:30 PM	Jazz Concert -- *Brechemin Auditorium, Music Building*		

Tuesday, July 31			
	210 Kane Hall	220 Kane Hall	120 Kane Hall
8:30 AM	DDT	Ignition Phenomena	Premixed Turbulent Flames III
10:10 AM	Coffee Break		
10:30 AM	Plenary Lecture: R.K. Hanson -- *Kane 120*		
11:20 AM	Shock Ignition	Chemistry in Flames I	Flames
12:35 PM	Lunch Break		
2:00 PM	Detonation Chemistry	Acoustic Phenomena	Reciprocating Engines
2:50 PM	Poster Session I / Refreshements -- *Walker Ames Room*		
3:40 PM	Shock Interactions	Dusty Shocks / Detonations	Multi-Phase Combustion I
4:55 PM	Sessions Adjourn the for day		

Wednesday, August 1			
	210 Kane Hall	220 Kane Hall	120 Kane Hall
8:30 AM	Detonation Initiation I	Non-Ideal Detonations / Fast Deflagrations	Effects of Acoustic Fields
10:10 AM	Coffee Break		
10:30 AM	Plenary Lecture: P. Roth -- *Kane 120*		
11:20 AM	Detonation Initiation II	Detonation Diffraction	Practical Combustion
12:35 PM	Lunch Break		
2:00 PM	Shock Initiation / SDT	Chemistry in Flames II	Non-Premixed Turbulent Flames I
3:40 PM	Adjourn to Excursion:		
	Puget Sound Cruise and Salmon Dinner, Tillicum Village on Blake Island		

Thursday, August 2			
	210 Kane Hall	220 Kane Hall	120 Kane Hall
8:30 AM	Pulse Detonation I	Laminar Flames I	Non-Premixed Turbulent Flames II
10:10 AM	Coffee Break		
10:30 AM	Pulse Detonation II	Laminar Flames II	Non-Premixed Turbulent Flames II
12:35 PM	Lunch Break		
2:00 PM	Pulse Detonation III	Laminar Flames III	Validation of Reduction Procedures
2:50 PM	Poster Session II / Refreshements -- *Walker Ames Room*		
3:40 PM	Pulse Detonation IV	Swirling and Enclosed Flames	Soot and Fullerenes in Turbulent Flames
4:55 PM	Sessions Adjourn the for day		
6:30 PM	18th ICDERS Banquet (optional ticket event)		

Friday, August 3			
	210 Kane Hall	220 Kane Hall	120 Kane Hall
8:30AM	RAMAC I	Laminar Flames IV	Turbulent Spray and Jet Flames I
10:10 AM	Coffee Break		
10:30 AM	RAMAC II	Flame Interactions / Explosions	New Devices and Methods
12:35 PM	Lunch Break		
2:00 PM	Heterogeneous Combustion	Secondary Combustion	Multiphase Combustion II
3:15 PM	Break		
3:40 PM	Detonation Hazard	Numerical Computations	Transonic and Supersonic Combustion
4:30 PM	Colloquium Sessions Adjourn		
4:45 PM	Farewell Party -- *Walker Ames Room*		

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The following journals encourage submissions of full-length articles of papers which have been presented at the 18th ICDERS:

Combustion Science and Technology
Combustion Theory and Modelling
Shock Waves

Authors seeking archival publication should submit their full-length manuscript to the designated special editor of the journal whose content is most relevant to their paper. Submitted manuscripts will be peer reviewed, and if accepted may be subject to revision, following the procedures of the relevant journal.

Authors should inform the special editor, by email, of their intent to submit a manuscript for review on or before the end of the Colloquium. The email message should include the title of the manuscript, the names and contact address of the authors. Prior to submitting a manuscript, authors should review the guidelines of the special editors of the relevant journal.

As reviewed and revised manuscripts must conform to the stylistic standards of the relevant journal, authors should also consult instructions on the journal website to ensure that their manuscript conforms to that journal's standards.

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